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2.	Patent application number *(The Patent Office will fill this part in)*	10 FEB 2004 0402858.5
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	CHURCHILL DRILLING TOOLS LIMITED 33 ST SWITHINS STREET ABERDEEN AB10 6XL SCOTLAND UNITED KINGDOM
	Patents ADP number *(if you know it)*	8558734001
	If the applicant is a corporate body, give the country/state of its incorporation	UNITED KINGDOM
4.	Title of the invention	DOWHOLE TOOL
5.	Name of your agent *(if you have one)* "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	CRUIKSHANK & FAIRWEATHER 19 ROYAL EXCHANGE SQUARE GLASGOW G1 3AE SCOTLAND UNITED KINGDOM
	Patents ADP number *(if you know it)*	547002

6. Priority: Complete this section if you are declaring priority from one or more earlier patent applications, filed in the last 12 months.

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. Divisionals, etc: Complete this section only if this application is a divisional application or resulted from an entitlement dispute (see note f)

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Continuation sheets of this form	
Description	37
Claim(s)	
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Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent (Patents Form 7/77)	
Request for a preliminary examination and search (Patents Form 9/77)	
Request for a substantive examination (Patents Form 10/77)	
Any other documents (please specify)	

11. I/We request the grant of a patent on the basis of this application.

Signature(s) CRUIKSHANK & FAIRWEATHER — Date 9 FEBRUARY 2004

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ANDREW SHANKS

0141 221 5767

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DOWNHOLE TOOL

FIELD OF THE INVENTION

This invention relates to a downhole tool, and embodiments of the invention relate to a flow-actuated downhole tool, most typically a bypass tool.

BACKGROUND OF THE INVENTION

In the oil and gas industry, bores are drilled from surface to access subsurface hydrocarbon-bearing formations. In such a drilling operation, a drill bit is mounted on the end of a long "string" of pipe sections, and may be rotated from surface or by a motor located adjacent the drill bit. Drilling fluid or "mud" is pumped from surface down through the tubular string, to exit the drill bit via jetting nozzles. The drilling fluid then passes back to surface via the annulus between the drill pipe string and the bore wall. The drilling fluid serves a number of purposes, one being to carry drill cuttings away from the drill bit and then up through the annulus to surface. For a number of reasons, and particularly in highly deviated or extended reach wells, drill cuttings will sometimes gather in the annulus, restricting the flow of drilling fluid to surface and causing numerous other problems.

One method of clearing drill cuttings from the annulus is to provide one or more bypass tools in the drill string. These tools allow drilling fluid to flow directly into the annulus from an intermediate part

of the drill pipe string, without having to pass through the drill bit and other tools normally located towards the end of a drill string, which tools collectively form a bottom hole assembly (BHA). As a result, the fluid entering the annulus via the bypass tool is at higher velocity and is more effective at carrying and clearing the drill cuttings from the annulus. Bypass tools may also be used in other circumstances where it is desirable or necessary to circulate or supply fluid to the annulus without passing the fluid through the BHA.

There have been many proposals to provide fluid actuated bypass tools relying on a differential pressure force created by the flow of fluid through the tool to open the tool, usually by translating a sleeve to permit flow through a number of side or flow ports in the wall of the tool body. In some proposals the string bore may be completely blocked to actuate the tool, for example by dropping a ball from surface to land on a seat and create a piston which is pushed downwards by fluid pressure above the ball. The ball may subsequently be displaced, for example by squeezing the ball through the seat. This form of tool may be necessary where it is desired to circulate materials, for example lost-circulation material (LCM), that might damage the BHA, or the BHA includes flow actuated tools which it is preferred to have inoperative during the bypass operation. In other tools, the string bore may remain open while the flow ports are open, such that the flow is divided between the flow ports and the string bore, with the majority of flow usually being directed through the flow ports.

Other than tools adapted to be completely closed by a ball or the like, there are two main mechanisms available for creating a flow activated differential pressure in a tool. The first is by providing a flow restriction, usually a sleeve defining a nozzle, inside the tool. The nozzle creates a distinct pressure drop due to the fluid being forced through the narrow throat of the nozzle, and this pressure acts over the cross sectional area of the sleeve and creates a force in the same direction as the flow. The disadvantages of this method are that the presence of the nozzle creates an additional pressure drop in the string and also the nozzle creates a bore restriction within the string, both of which are undesirable.

The other mechanism for creating a flow activated differential pressure is to utilise the differential pressure between the inside and the outside of the pipe. This differential pressure acts via a differential piston, which is a common feature in many downhole tools. Such a piston allows the lower external pressure to act on part of the area of the sliding sleeve and the higher internal pressure to act on an opposing part of the sleeve, so creating a pressure differential force that may be utilised to move a valve sleeve. A differential piston can be configured to move in either direction relative to the direction of flow. This mechanism has neither of the major drawbacks of the nozzle method in that it can provide very significant flow related forces without inducing losses in the flowing fluid and without restricting the tool bore.

However, there a number of difficulties and uncertainties associated with the use of differential pistons, as discussed below. In general terms,

the pressure at any point in the pipe or annulus is equal to the sum of all of the pressure losses created downstream of that point by the fluid flowing through the remainder of the fluid circulation path; this is known as the backpressure. Different parts of the string will create different degrees of pressure loss, but every element of the fluid flow path will contribute some pressure loss: each length of pipe, each narrowing at a screwed connection, and every piece of equipment that is part of the drill string will create a pressure loss. In general, where the flow area is small the pressure losses will be greatest. Each of these pressure losses will increase exponentially with the flow rate, such that doubling the flow rate quadruples the pressure loss.

Thus, it can be seen that the magnitude of the opening force provided by a differential piston is largely dependent on the geometry of the pipe and hole below the tool which incorporates the piston, and so will be different for every well. However, in addition, and far more significantly, the force created by a differential piston-actuated bypass tool will only exist when the flow ports are closed. The instant the ports open, flow will divert through the ports, and consequently the flow rate will reduce through the string below the tool. If, for example, the flow is split 50:50, the differential pressure force produced by the piston will suddenly be ¼ of the force produced the instant before, when the ports were closed. Thus, the port opening force will suddenly be ¼ of the force required to overcome the spring and open the port: opening the side ports relieves the pressure that powers the movement of the sleeve to open the port, so the sleeve immediately moves to close the ports. Directly the sleeve has closed

the ports the differential pressure force will be restored and the sleeve will be moved to open the ports, and so on. However, if the tool is provided with any form of cycling control system the sleeve may shuttle back and forward until stabilising. Clearly, if the sleeve stabilises in the closed position the tool cannot be used as a bypass tool. If the sleeve shuttles to a stable position in which the sleeve is locked open it will not then be possible to close the ports as there is no differential pressure available to overcome the spring force and release the sleeve.

Thus, despite the attendant disadvantages, the most effective flow actuated bypass tools tend to include nozzles or other flow restrictions to create a fluid-flow related opening force: see, for example, applicant's WO 01/06086, the disclosure of which is incorporated herein by reference. However, particularly in circumstances where there is an elevated pressure differential between the tool interior and the annulus, such bypass tools often prove difficult to open. Furthermore, in circumstances where it is only possible to achieve a restricted fluid circulation flow rate, and thus a restricted fluid pressure force across the nozzle, it may be difficult to achieve the force necessary to open the bypass tool.

Even where a bypass tool is successfully opened in a high pressure differential situation, there is also often a problem relating to the initial flow of fluid through the tool flow ports: as the tool opens, the high differential pressure will induce a high velocity flow, which may result in erosion of areas of the tool, and the high velocity flow

may also wash out the seals adjacent the flow ports, one of which must pass across the flow ports as the tool is opened. In particular, parts of the seals may be displaced and pushed or sucked through the flow ports, such that when the tool subsequently closes the seals are guillotined, rendering the tool useless.

Thus, although flow-operated bypass tools are currently being successfully used by many operators, the wider use of such tools is restricted by a number of limiting operating parameters, primarily differential pressure and available flow rate, and operation beyond these boundaries tends to have a negative effect on tool reliability and dependability. Accordingly, it is among the objectives of embodiments of the present invention to provide bypass tools capable of operating reliably over a wide range of hydrostatic pressures, differential pressures and flow rates.

SUMMARY OF THE INVENTION

According to the present invention there is provided a downhole tool comprising:

a body defining a bore and comprising a valve arrangement including at least one flow port in the wall of the body and whereby the port may be selectively opened and closed; and

a variable flow restriction in the bore, the degree of restriction tending to decrease as pressure across the restriction increases.

Thus, the tool may be arranged to allow flow through the flow port, such that fluid may flow between the body bore and the tool exterior, or the flow port may be closed. In certain embodiments of the invention the variable flow restriction may be utilised to control fluid flow through the body bore below the ports.

Preferably the tool body is adapted to form part of a string of tubing, such as a string of drill pipe. Thus, during a drilling operation, fluid may be pumped from surface through the drill string, and may be selectively redirected through the flow port. As will be described, the variable flow restriction may be adapted to selectively close the bore below the flow port, such that all of the fluid may be directed through the flow port, or may permit a proportion of the fluid to pass through the bore while a proportion of the fluid is redirected through the flow port. In other embodiments the variable flow restriction may be utilised to create a pressure differential and the resulting force utilised to actuate the valve arrangement.

Preferably, the valve arrangement is biased towards one of an open configuration and a closed configuration. It is generally preferred that, for well control purposes, the flow port is normally closed. However, there are situations in which it is desirable or advantageous for the flow port to be normally open, as will be described. The valve arrangement may be initially retained in one of the open configuration and the closed configuration, and after release may move to the other configuration.

Preferably, the valve arrangement includes control means for at least one of controlling the sequence of operation of the valve arrangement and

controlling the response of the valve arrangement to actuation forces. The control means may comprise a cam arrangement between a movable valve element and the body, and may comprise a cam arrangement between a valve actuator and a valve element.

Preferably, the valve arrangement is flow-actuated, and most preferably the valve arrangement is adapted to be actuated by a differential fluid pressure acting across at least one flow restriction in the bore, which flow restriction may be provided by the variable flow restriction or by a further flow restriction, or by a combination of the variable flow restriction and a further flow restriction. The further flow restriction may be a fixed restriction or may be a variable restriction. Thus, the variable flow restriction may operate independently of the valve arrangement or may be operatively associated with the valve arrangement. Where provided, the further flow restriction may be integral with the tool body, or may be provided as a separate unit to be located in the body as and when required.

In other embodiments of the invention the valve arrangement is adapted to be actuated by one or more other means, including but not limited to a spring, which may be a mechanical spring or a fluid spring, an electric motor, weight or tension.

The variable flow restriction may feature a tight configuration in which the restriction completely closes the body bore, or in the tight configuration the flow restriction may still allow flow through the bore. If the variable flow restriction is positioned above or upstream of the flow ports, the former arrangement may be used to prevent flow of fluid through both the bore and the flow port, and if the variable flow restriction is

a flow restriction across which a differential pressure may be developed, the resulting force being utilised to release the valve element retaining means. In one embodiment, the flow restriction is provided in a unit that may be located in the tool only when it is desired to release the valve element retaining means.

Preferably, the valve arrangement includes control means for at least one of controlling the sequence of operation of the valve arrangement and controlling the response of the valve arrangement to actuation forces. The control means may comprise a cam arrangement between the valve element and the body, and may comprise a cam arrangement between a valve actuator and the valve element.

According to a further aspect of the present invention there is provided a fluid-actuated tool comprising:

a body comprising a valve arrangement including at least one flow port in a wall of the body and whereby the port may be selectively opened and closed; and

a flow restriction operatively associated with the valve arrangement and upstream of the at least one flow port whereby fluid flow through the restriction creates a port opening force and whereby the flow restriction has a variable, flow-related configuration.

In use, the provision of a flow restriction having a flow-related configuration offers many advantages. In particular, at lower flow rates it may be necessary or desirable to have a tight or narrow restriction, in order to achieve the differential pressure force across the restriction

necessary to open the port. However, once the port is open it may then be possible to increase the flow rate. If the increase in flow rate is accompanied by an increase in the flow area of the restriction the port opening force may be maintained while the losses created by the restriction are minimised. In certain embodiments it may be possible to selectively isolate the valve arrangement from the restriction, such that at higher flow rates the restriction may open up, without affecting the valve configuration; in particular, the port may remain closed at higher flow rates. This is of particular advantage in downhole bypass tools, where difficulties in circulating drilling fluid may be the result, or cause, of low fluid circulating flow rates. However, if the bypass tool is provided with a particularly tight fixed flow restriction this will only exacerbate the problem during normal operations when the bypass tool remains closed, due to the high level of losses induced by the restriction. Furthermore, while a tight nozzle will have a significant effect when the bypass tool is closed, due to the exponential increase in losses with increasing flow rate, the presence of such a tight fixed flow restriction will have a far greater effect when bypassing and pumping faster.

Preferably, the tool is a downhole tool, though embodiments of the invention may find application in surface or sub-sea applications.

Preferably, the tool is a bypass tool, though embodiments of the invention may find application in other tools, such as chemical injection tools.

Preferably, the valve arrangement may be selectively isolated from the flow restriction such that flow through the restriction does not impact on the valve configuration. This is useful in circumstances where it is not necessary or desirable to open or close the port, such that an operator may vary the flow rate through the restriction in the knowledge that such flow rate variations will not inadvertently open the port. Preferably, the means for selectively isolating the valve arrangement from the flow restriction is flow actuated. In a downhole application, this allows an operator to control the means from surface simply by varying the pump rate, for example by increasing or decreasing the pump flow rate, or simply by turning the pumps on and off. The means may take any appropriate form, at the simplest level providing means for releasably retaining the valve arrangement in an initial configuration, Such means may include shear or sprung pins. In preferred arrangements however, means are provided for controlling the interaction between the restriction and the valve arrangement, for example by providing a cam arrangement or providing a J-slot arrangement, such that the means may be cycled between different configurations. In a preferred arrangement, the means is arranged such that it may be continuously cycled, for example by providing a 360-degree or otherwise continuous slot and follower pin.

The flow restriction may take any appropriate form, and is preferably in the form of a nozzle or choke. Preferably, the configuration of the restriction is variable by changing the flow area

defined by the restriction in response to flow-related forces experienced by the restriction. Preferably, the restriction normally defines a smaller flow area, which may be zero; in this case there is normally no flow through the restriction. The restriction may be spring biased towards this smaller flow area configuration; a given flow rate will create a greater differential pressure force across the restriction in this configuration. On experiencing a pressure differential force above a predetermined level the restriction may be reconfigured to define a larger flow area, and thus present less of an impediment to flow. This may be achieved by mounting part of the restriction on a spring, such that the part moves when the differential pressure force acting on the part overcomes the spring force. Movement of the part may be damped, for example by locating the spring in a chamber which changes volume as the part moves, and controlling the rate of flow of fluid from or into the chamber.

Preferably, the flow restriction comprises at least two relatively movable parts, the parts being movable to vary the degree of restriction. In one embodiment, the restriction comprises an orifice and a spear, the orifice being axially movable relative to the spear to vary the area of the annulus between the spear and the orifice.

The flow restriction may be integral with the tool body. Alternatively, the flow restriction may be provided as a separate unit and may be located in the tool body as and when required, for example in a somewhat similar manner to the sleeve as described in applicant's

WO 01/06086. Thus, the tool body may be provided in, for example, a drill string and remain dormant, presenting little or no restriction to fluid flow, until required. The restriction, which may take the form of a sleeve incorporating a variable orifice, may then be pumped from surface through the string to land on and engage with the body. If desired, the restriction may also be retrievable.

Preferably, the valve arrangement comprises a sleeve, which is one or both of axially and rotatably movable relative to a body wall portion. One or both of the sleeve or body wall may define the one or more flow ports. The sleeve may be biased towards a position to close the ports. Preferably, the sleeve is mounted internally of the body. Seals may be provided between the sleeve and the body, to limit or prevent flow of fluid through the ports when the sleeve is positioned to close the ports. The seals may take a conventional form, for example seal members in the form of elastomeric O-rings or chevron seals. In one embodiment of the invention, at least on one side of the one or more flow ports, there are no seal members provided. Rather, the cooperating sleeve and body surfaces are very close fitting. Typically, this is achieved by forming the surfaces of a relatively hard material, such as tungsten carbide or a ceramic, and then grinding the surface down to a high tolerance. As a result, the clearance between the annular surfaces may be the order of a few thousandths of an inch. Under pressure, fluid will flow through this "micro" annulus. However, because of the limited dimensions of the annulus the fluid velocity will be low, typically in the

order of 1 inch/second, such that the energy and the volume of the leakage will be low. The low flow velocity and the hard surfaces will limit or prevent wear of the surfaces.

According to another aspect of the present invention there is provided a downhole differential pressure seal arrangement between relatively movable surfaces, the seal arrangement comprising cooperating relatively movable surfaces defining a clearance therebetween, the clearance being selected to permit a low velocity and low energy flow of liquid therebetween.

The seal arrangement may be provided in a bypass tool or the like. In a bypass tool, the seal arrangement may be provided in a valve arrangement including at least one flow port in a wall of the body and whereby the port may be selectively opened and closed. The seal arrangement is preferably provided on the side of the flow port which is initially opened, that is at least one of the surfaces will be in the initial flow path through the port. With conventional seal members, particularly elastomeric O-ring seals, there is a risk that the initial high velocity flow through the opening port will wash part of the seal member into the port, such that the seal member is guillotined when the port is subsequently closed. However, with this aspect of the invention there is no separate seal member, such that there is no risk of this form of failure.

Furthermore, although not wishing to be bound by theory, the applicant believes that replacing one or more conventional seals in a

downhole differential pressure seal arrangement will significantly decrease the level of force necessary to move the adjacent sealed parts, as described below. In a conventional downhole tool, such as a flow actuated bypass tool, a sleeve is mounted within the tool body and is axially movable relative to the body to open or close flow ports; typically, both the sleeve and the body define flow ports which may be aligned to provide a flow path between the tool bore and the surrounding annulus. The sleeve will typically be spring-biased towards the closed position. The sleeve may be coupled to a nozzle or choke such that flow through the choke creates a differential pressure across the orifice, tending to move the sleeve to open the flow ports. Conventionally, calculations relating to the flow rate necessary to move the sleeve to the open position are made with reference to the return spring force. However, the applicant has identified that there are other significant forces which must be considered, in particular the frictional forces created by the seals between the sleeve and the body, and which forces act to resist movement of the sleeve relative to the body. Conventional seals are energised by pressure, and in a downhole bypass tool the pressure acting on the seals has two main elements, hydrostatic pressure and differential pressure, that is the pressure created by the head of fluid in the bore above the tool, and the differential pressure between the interior of the tool and the exterior of the tool, which will vary depending upon a number of conditions, including the sum of pressure drops below the tool and drilling fluid flow rate. The hydrostatic

pressure acts on both sides of the seals and creates a level of friction that varies with mud weight and vertical depth and that must be overcome to move the sleeve relative to the tool body, both when opening and closing the tool. At low differential pressures, seal friction caused by the differential pressure is relatively low and easily predicted. However, as differential pressure increases, the seal friction increases exponentially.

While a degree of seal friction is useful, as it tends to damp movement of the sleeve, once the combined frictional effects induced by elevated hydrostatic and differential pressures are taken into account it becomes apparent why existing bypass tools become unpredictable and unreliable at higher hydrostatic and differential pressures.

This aspect of the invention obviates the pressure-related friction associated with conventional seals, thus facilitating operation of such downhole tools. In particular, the seal arrangement of the present invention reduces the forces required to open such tools, particularly at higher differential pressures, and renders the tool operating force substantially independent of pressure. It is thus possible to provide the necessary tool opening force, at a particular flow rate, and independent of hole depth, mud weight and pressure drops below the tool, using a larger choke, for example a 1 inch diameter choke may suffice whereas a 7/8 inch choke, or smaller choke, would be required if conventional seals were being used. Of course this offers the advantage that the pressure losses induced by the choke are also reduced. In other cases,

the invention may make it possible to open a choke-actuated bypass tool at differential pressures which previously made operation of such a tool impractical or impossible.

In certain embodiments, it may be useful to combine a seal arrangement in accordance with this aspect of the invention with a conventional seal. As noted above, within certain parameters conventional seals may provide a useful damping effect. In other embodiments, the damping effect normally supplied by a conventional seal may be provided by other means, for example a snap ring.

Although reference is made herein primarily to bypass tools and the like it will be apparent to those of skill in the art that the various aspects of the invention have application in other tools and devices. In particular, in a further aspect of the invention there is provided a tool comprising a body including a fluid actuated device including a flow restriction whereby fluid flow through the restriction creates an actuating force and whereby the flow restriction has a variable, flow-related configuration.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figures 1 – 3 are graphs illustrating opening forces produced by chokes of different sizes in conventional bypass tools;

Figure 4a is a sectional view of a bypass tool in accordance with an embodiment of the present invention, shown in an initial closed configuration;

Figures 4b is a development of a cam arrangement for controlling the interaction between a flow restriction and a valve arrangement of the bypass tool of Figure 4a;

Figure 4c is an enlarged sectional view of the flow restriction of Figure 4a;

Figure 5a is a sectional view of the bypass tool of Figure 4a, showing the bypass tool open;

Figures 5b is a development of the cam arrangement of the bypass tool of Figure 5a;

Figure 6a is a sectional view of the bypass tool of Figure 4a, showing the bypass tool in a second open configuration;

Figures 6b is a development of the cam arrangement of the bypass tool of Figure 6a;

Figure 7a is a sectional view of the bypass tool of Figure 4a, showing the bypass tool in a second closed configuration;

Figures 7b is a development of the cam arrangement of the bypass tool of Figure 7a;

Figure 8 is a sectional view of a bypass tool in accordance with a further embodiment of the present invention, showing the tool in an initial closed configuration;

Figures 9 and 10 are sectional views of alternative flow restrictions in accordance with further embodiments of the present invention;

Figure 11 is a sectional view of a bypass tool in accordance with an embodiment with an embodiment of the invention;

Figure 12a is a sectional view of a bypass tool in accordance with an embodiment of the invention, shown in an initial locked closed configuration;

Figure 12b is a development of a cam arrangement for controlling the interaction between a flow restriction and a valve arrangement of the tool of Figure 12a;

Figure 13 is a sectional view of the bypass tool of Figure 12a, showing the tool being unlocked, ready to open;

Figure 14 is a sectional view of the bypass tool of Figure 12a, showing the tool in a first open configuration;

Figure 15a is a sectional view of the bypass tool of Figure 12a, shown in a second open configuration;

Figure 15b is a development of the cam arrangement of the bypass tool of Figure 15a;

Figure 16a is a sectional view of the bypass tool of Figure 12a, shown in a third open configuration;

Figure 16b is a development of the cam arrangement of the bypass tool of Figure 16a;

Figure 17a is a sectional view of the bypass tool of Figure 12a, shown in a second closed configuration;

Figure 17b is a development of the cam arrangement of the bypass tool of Figure 17a;

Figure 18 is a sectional view of a bypass tool in accordance with an embodiment of the invention; and

Figures 19 and 20 are sectional views of further tools in accordance with embodiments of the invention.

DETAILED DESCRIPTION OF THE DRAWINGS

Reference is first made to Figure 1 of the drawings, which is a graph showing the conventional understanding of opening forces in a downhole bypass tool. In particular, the tool features a sleeve provided in combination with a choke, this sleeve being normally spring biased to close flow ports in the tool body wall. By increasing the flow rate through the choke, the differential pressure force developed across the choke may be increased, and when this force is higher than the spring force provided by the return spring the sleeve will move and open the flow ports.

Conventionally, a tool designer will simply choose the largest choke or nozzle which will open the tool at the desired flow rate, based on the information as portrayed in Figure 1. However, the present

applicant has identified that this is a gross oversimplification of bypass tool operation.

Seals are provided between the sleeve and tool body, and these seals are energised by pressure; the higher the pressure the harder the seals will grip the mating surfaces, thus preventing leakage. However, the harder the seals grip, the more friction increases to prevent relative movement.

Seals in downhole tools experience both hydrostatic and differential pressure. As may be seen from the graph of Figure 2, the hydrostatic friction, resulting from the seals being subjected to pressure from the head of fluid standing in the well bore, is constant at a certain depth and mud weight. However, the seal friction due to differential pressure varies exponentially with flow rate. Thus, as may be seen from Figure 2, at a high differential pressure (4000psi at 125 gpm) a $^{7}/_{8}$ inch choke will never produce sufficient force to open the tool ports.

Accordingly, in order to open the tool ports in a high differential pressure environment, a very tight choke or nozzle is required. This is however self-defeating as at high flow rates a very tight choke results in significant pressure losses; the reason for providing a bypass is to relieve pressure.

Another issue which must be considered when determining the operating parameters of a flow activated bypass tool is that one of the seals will have a port travel across the seal as the port is opened and closed. As conventional seal members are elastomeric and energised to

the point of opening there is a tendency for the seal members to get sucked into the port and sealing function is subsequently lost. Better bypass tools are designed with this in mind, however even the best tools tend to have an upper differential pressure limit of around 2000 psi. As is apparent from the graphs shown in Figure 3, there remains the possibility of seal failure by this mechanism in certain circumstances.

From the above it is apparent that high differential pressures create a number of technical difficulties for the successful and reliable operation of a flow activated bypass tool.

As noted above, one of the main reasons for using a bypass tool is to relieve pressure, in particular to avoid the pressure losses incurred in pumping the drilling fluid through the BHA, in order to increase the flow rate in the upper annulus, which is often of a larger cross sectional area. In circumstances where there is a large differential pressure prior to opening the bypass tool, the available flow rate is usually low, thus the available opening force is correspondingly low.

Thus, the greater the need for the bypass tool to open, the less force available to open the tool and the greater the frictional resistance to opening. Various aspects of the present invention are intended to address these difficulties, as described below.

Reference is now made to Figure 4a of the drawings, which is a sectional view of a bypass tool in accordance with a preferred embodiment of the present invention. The tool 10 comprises a generally cylindrical body 12 defining an axial through bore 14. The body 12 is

adapted to form part of an otherwise conventional drill string and thus features pin and box ends 16, 17 to allow coupling to adjacent pipe sections. Provided within the body 12 is a valve arrangement 18 including a valve sleeve 20. As will be described, flow ports 22 in the sleeve 20 may be aligned with flow ports 24 in the body 12 to allow drilling fluid to flow directly from the tool bore 14 into the annulus 26 which, in use, will be defined between the exterior of the tool 10 and the surrounding bore wall.

The tool is flow activated by means of a flow restriction 30. The tool body 12 may initially be provided in a drill pipe string without the flow restriction 30, such that there is no impediment to flow of drilling fluid through tool 10. However, when bypass is required, the flow restriction 30 may be pumped down to the tool 10 from surface, and Figure 4a shows the flow restriction 30 just before it engages with the tool body 12.

The valve sleeve 20 is normally biased to an upper position, as illustrated in Figure 4a, by a compression spring 32. In this position, the wall of the sleeve 20 bridges the flow ports 24. A conventional O-ring seal 34 is provided on the exterior of the sleeve 20 for location below the flow ports 24. However, the seal 36 above the flow ports 24 is of a different configuration. In particular, the seal 36 is provided by two co-operating surfaces 38, 39 of a harder material, in this example tungsten carbide, which have been ground to a high tolerance such that the annular gap between the surfaces 38, 39 is of the order of a few

thousandths of an inch. In use, with the differential pressure acting across the seal 36, drilling fluid will flow through this micro-annulus 40 however, because of the minimal clearance, the fluid velocity will be low, in the order of 1 inch per second. Accordingly, the volume and kinetic energy of the leaking fluid will be correspondingly low. Furthermore, because the surfaces 38, 39 are very hard, there will be little if any damage to these surfaces. Thus, equilibrium will be maintained across the seal 36 and under normal drilling conditions the leakage of fluid through the seal 36 will not create any problems and will effectively remain unnoticed.

The upper end of the sleeve 20 co-operates with a restriction landing sleeve 40 having a profile 42 adapted to engage with a corresponding profile 44 provided on the upper end of the flow restriction 30. The landing sleeve 40 is biased towards an upper position relative to the body 12 by a further compression spring 46. The two sleeves 20, 40 interact via a track and pin arrangement, a development of which is illustrated in Figure 4b of the drawings. In particular, the upper end of the sleeve 20 features a number of radial inwardly directed pins 48 which engage with a continuous cam track 50 formed on an outer surface of the landing sleeve 40.

Reference is now also made to Figure 4c of the drawings, which illustrates the flow restriction 30 in greater detail. The flow restriction 30 comprises a cylindrical collar 52 that provides mounting for a central spear 54 via an apertured plate 53. Mounted coaxially within the collar

52 is a sleeve 56, the upper end of which defines an orifice 58. A compression spring 60 acts between the sleeve 56 and the collar 52, to bias the sleeve 56 upwardly such that the orifice 58 is positioned around the spear 54. Thus, the flow restriction 30 normally defines a relatively tight choke, the area of the choke being the annulus defined between the orifice 58 and the spear 54.

The spring 60 is located within an annular spring cavity 61. To permit movement of the sleeve 56 relative to the collar 52 it is of course necessary for fluid to be able to pass from and into the cavity 61, as the volume of the cavity 61 changes. However, by providing a relatively small orifice through which fluid must flow from the cavity 61, it is possible to damp the movement of the sleeve 56.

As noted above, the tool body 12 will normally be incorporated in a drill string and the flow restriction 30 only pumped into the string when bypass is required. Reference is now made to Figure 5a of the drawings, which shows the flow restriction 30 engaged with the tool body 12. Furthermore, the flow of fluid through the tool bore 14 has created a differential pressure force across the restriction 30. Initial downward movement of the flow restriction 30 induced by this differential pressure force compresses the spring 46 and moves the pins 48 from the initial dormant position 48a in the cam track 50 (Figure 4a) to a second position 48b where further axial movement of the restriction 30 and landing sleeve 40 produces corresponding movement of the valve sleeve 20, resulting in compression of both springs 32 and 46, and

alignment of the flow ports 22, 24. Clearly, such movement of the valve sleeve 20 will only occur when the spring force provided by both springs 32, 46 has been overcome, in addition to the frictional resistance to movement provided by the O-ring seal 34. The other seal 36 will provide little or no resistance to movement.

If the operator continues to increase the flow rate through the string, the differential pressure force across the restriction 30 will continue to increase. Due to the sleeve 40 landing out on a shoulder 62 of a sleeve 64 fixed to the tool body 12, further axial movement of the sleeves 20, 40 is not possible. However, once the differential pressure force exceeds the orifice closing force provided by the spring 60, the sleeve 56 will be moved downwards to the position illustrated in Figures 6a of the drawings; the spring 60 is selected such that the tool is open before the there is any movement of the sleeve 56. It will be noted that the sleeve 56 has been pushed downwardly beyond the end of the spear 54, such that the restriction to flow provided by the flow restriction 30 has now been considerably reduced. Thus, the pressure losses across the flow restriction 30 will be considerably less than they would have been had the restriction 30 been fixed in the configuration as illustrated in Figures 4 and 5.

If it is desired to close the flow ports 24 all that is required is for the operator to reduce the drilling fluid flow rate through the string and the tool 10 to the level where the differential pressure force across the flow restriction 30 is less than the return forces provided by the various

springs 60, 46 and 32; in practice, this will tend to be achieved by simply turning off the pumps. The sleeves 20, 40 will return to their original positions as illustrated in Figures 4a, however, the follower pins 48 will now be in the position illustrated by numeral 48c in the cam track 50, as illustrated in Figure 6b.

If the operator then turns up the drilling fluid pumps once more, the flow restriction 30 together with the landing sleeve 40 will once again be pushed downwardly relative to the tool body 12. However, due to the location of the pins 48 in the cam track 50, the landing sleeve 40 may move downwardly, while the pin 48 moves towards position 48d (Figure 7b), without inducing corresponding movement of the valve sleeve 20, until the landing sleeve 40 itself lands out on the shoulder 62. Further increases in drilling fluid flow rate will result in the restriction sleeve 56 being moved downwards relative to the restriction collar 52, as is illustrated in Figure 7a of the drawings. Accordingly, in this configuration the pressure losses induced by the flow restriction 30 will be substantially less than would have been the case if the flow restriction was fixed in the configuration as illustrated in, for example, Figure 5a.

Reference is now made to Figure 8 of the drawings, which illustrates a tool 110 in accordance with an alternative embodiment of the present invention. The tool 110 shares many features with the tool 10 described above. However, it will be apparent that in place of the conventional o-ring seal 34 of the tool 10, the tool 110 features a seal

illustrated in Figure 8. However, in the tool 410 the tool body 412 features a profile 470 towards the lower end of the tool adapted to engage with a flow restriction 230, as previously described with reference to Figure 9. It will be recalled that the flow restriction 230 is configured such that there is normally no flow permitted through the flow restriction, the orifice 258 defined by the upper end of the flow restriction sleeve 256 being only very slightly larger than the outer diameter of the spear 254. Thus, the restriction 230 will not permit flow through the tool 410 until the pressure differential across the restriction 230 is sufficient to compress the spring 260 and move the orifice 258 downwards and clear of the spear 254.

In use, the tool 410 is initially held in the closed position by the two main springs 432, 446 and a snap-ring 437 and is run into the bore without any restrictions being present within the tool 410. However, when the operator determines that bypass is required, the restriction 230 is pumped down from surface, followed by a second flow restriction 430, in this embodiment the restriction 430 featuring a fixed choke 458. The restriction 230 will land on the profile 470, while the restriction 430 will land on the landing sleeve profile 442.

Drilling fluid will only pass through the tool 410 if the differential pressure across the restriction 230 is sufficient to compress the spring 260 such that the orifice 258 is opened. The flow induced differential pressure forces created by the restriction 430 may then be utilised to move the sleeve 420 to align the flow ports 422, 424 to allow fluid to flow from the tool bore 414 directly into the annulus via the aligned flow ports 422, 424.

body 512 are misaligned, and any fluid flow through the tool 510 will be directed through the tool bore 514 to the drill string or pipe below the tool. From Figure 12a it will be noted that the initial configuration of the tool 510 is somewhat different from the tools described above, in that the sleeve flow port 522 is positioned below the body flow port 524. Also, it will be noted that the sleeve 520 defines an inner profile 521 and also that the sleeve 520 is initially locked relative to the body 512 by shear pins 537.

To open the tool 510, a restriction 230 is pumped from the surface down through the string to engage the profile 521. The resulting hydraulic shock will shear the pins 537 (Figure 13) as the restriction 230 lands. Immediately afterwards the orifice 258 will move down, allowing flow through the restriction 230, while maintaining the flow ports 522, 524 closed (this particular tool configuration not illustrated in the drawings). Subsequently turning off the flow allows the spring 532 to move the sleeve 520 upwardly to align the flow ports 522, 524, as illustrated in Figure 14 of the drawings. In this configuration, all of the fluid flowing down into the tool 510 will be directed into the annulus via the ports 522, 524, the restriction 230 preventing any fluid from flowing past the tool 510 and into the string bore below the tool.

If it is desired to close the flow ports 524, a further restriction 530 is pumped down the string from surface to engage with the sleeve profile 524, as illustrated in Figure 15a of the drawings. The restriction 530 is similar to the restriction 30 described above with reference to Figure 4c, and includes a sleeve 556 which is biased to co-operate with a spear 554 to

applied to the sleeve 520, and will tend to move the sleeve 520 to close the flow ports 524.

Furthermore, as the flow ports 524 are closed a differential pressure will tend to develop across the lower restriction 230, producing a further pressure differential force tending to move the valve sleeve 520 downwardly, until ultimately the flow ports 524 will be completely closed and the lower restriction 230 will open, as illustrated in Figure 17a of the drawings; the tool 510 is thus now configured such that all of the fluid flowing down through the string passes through the tool 510 into the string bore below the tool.

Reference is now made to Figure 18 of the drawings, which illustrates a tool 610 in accordance with another embodiment of the present invention. The tool 610 is similar to the tool 510 described above, with the exception that the upper second restriction 630 features a fixed diameter choke 658. This tool 610 will operate in substantially the same manner as the tool 510, however the energy losses induced by the restriction 630 will tend to be slightly higher than the losses induced by the variable restriction 530.

Reference is now made to Figure 19 of the drawings which illustrates a tool 710 in accordance with another embodiment of the present invention. The tool 710 is similar in configuration to the tool 610 described above, however it will be noted that the tool is provided without a lower restriction, and only features an upper restriction 730. The tool may thus function in a similar manner to the tool 510, but of course cannot be used to provide 100% bypass, as the bore below the flow ports 722, 724

Those of skill in the art will also recognise that the above described embodiments are merely exemplary of the present invention, and that various modifications and improvements may be made thereto without departing from the scope of the present invention. For example, in other embodiments the valve sleeve may be coupled to the body via a cam arrangement, to provided greater control of the movement of the sleeve, and this would permit, for example, the "normally-open" tools 510, 610, 710 and 810 to be maintained in a closed configuration in the absence of flow.

IBT Opening Forces

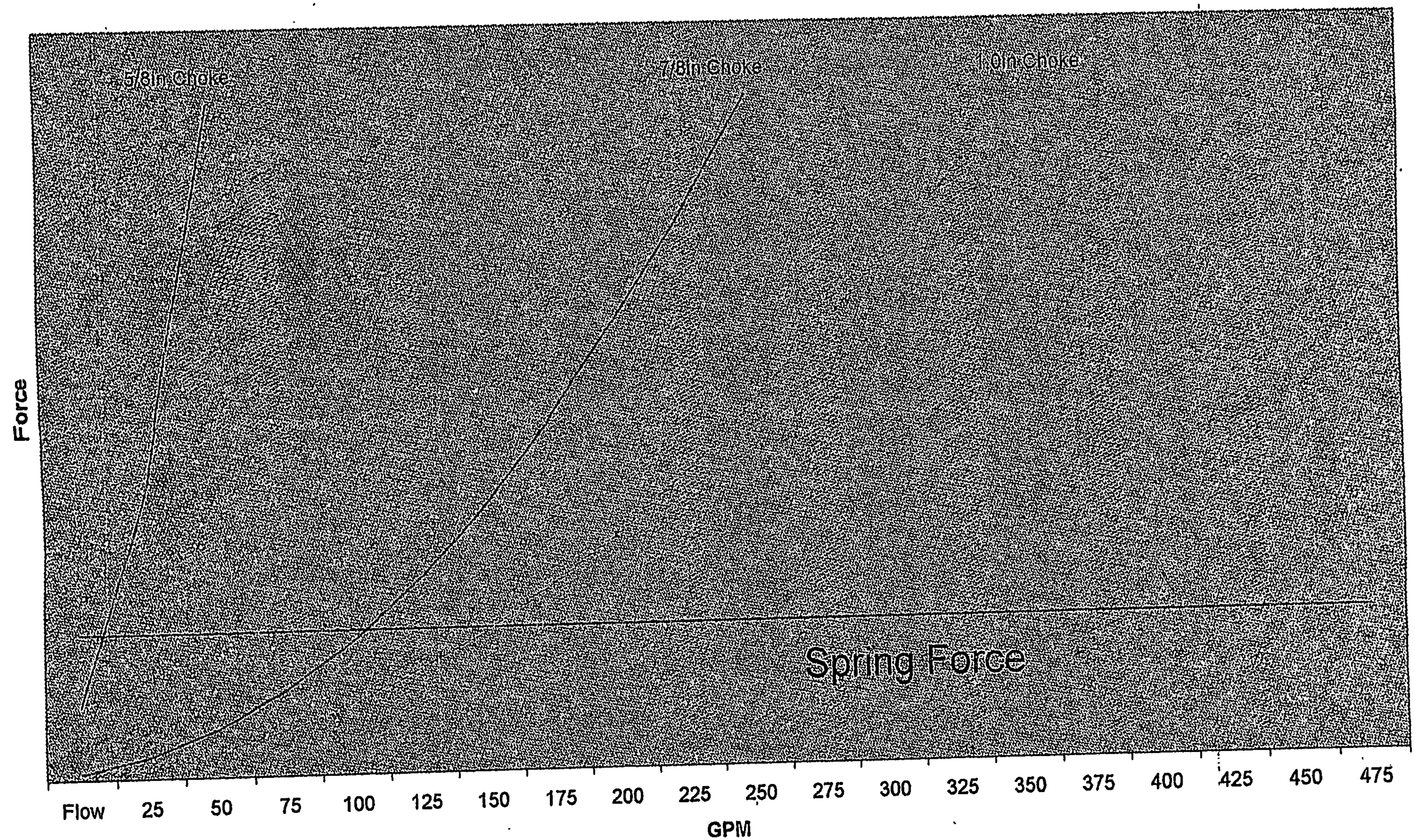


Figure 1

IBT Opening Forces

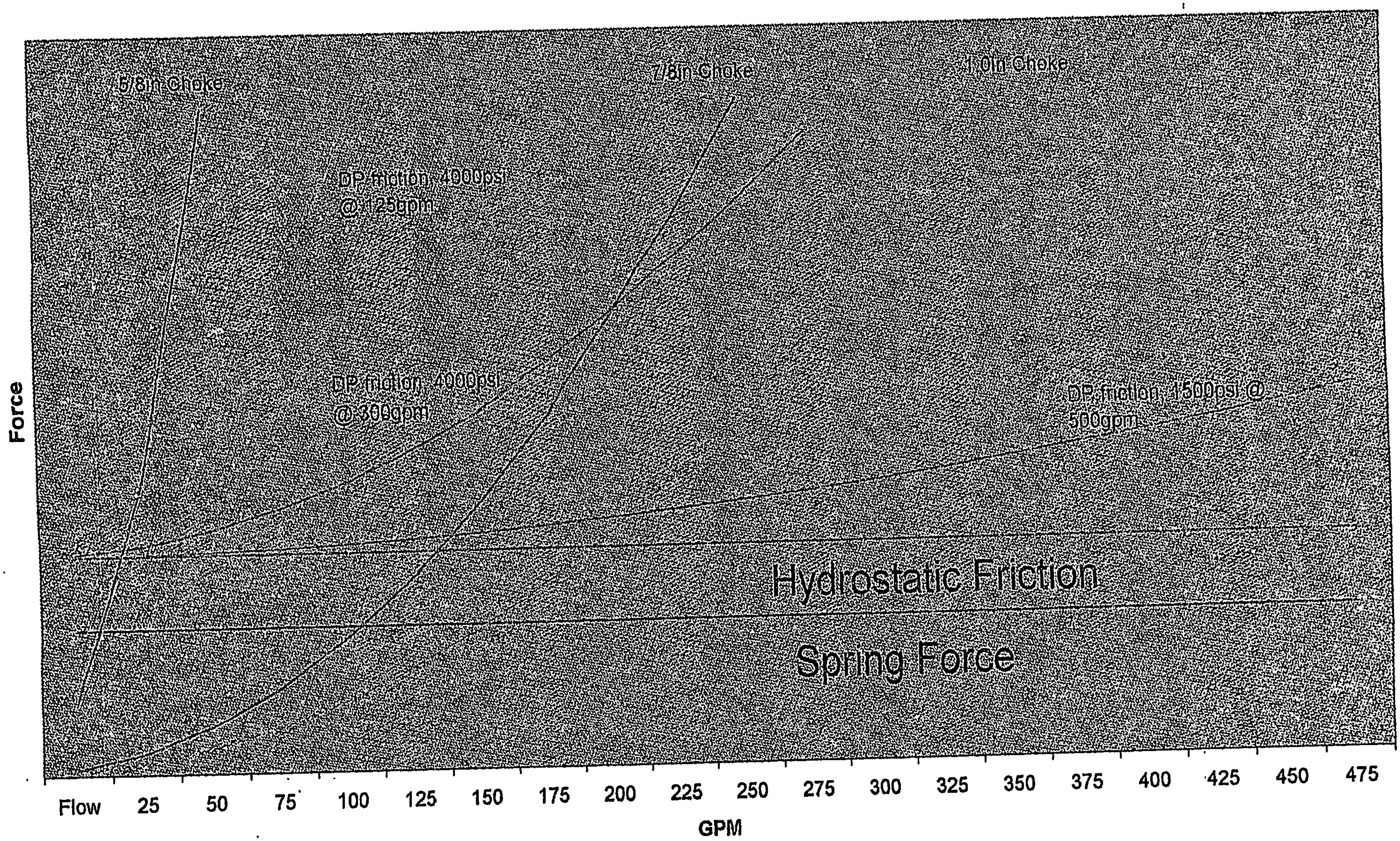


Figure 2

IBT Opening Forces

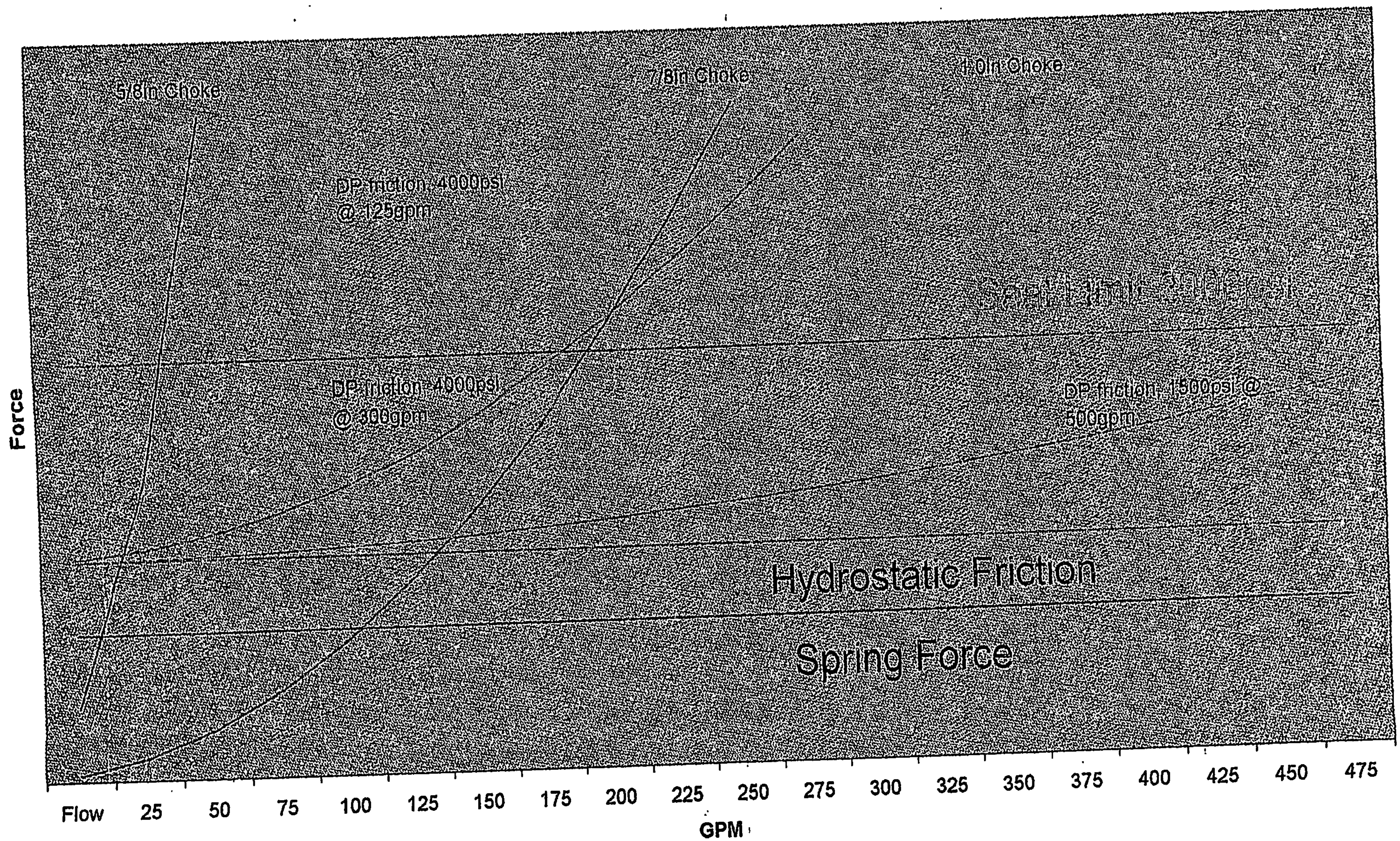


Figure 3

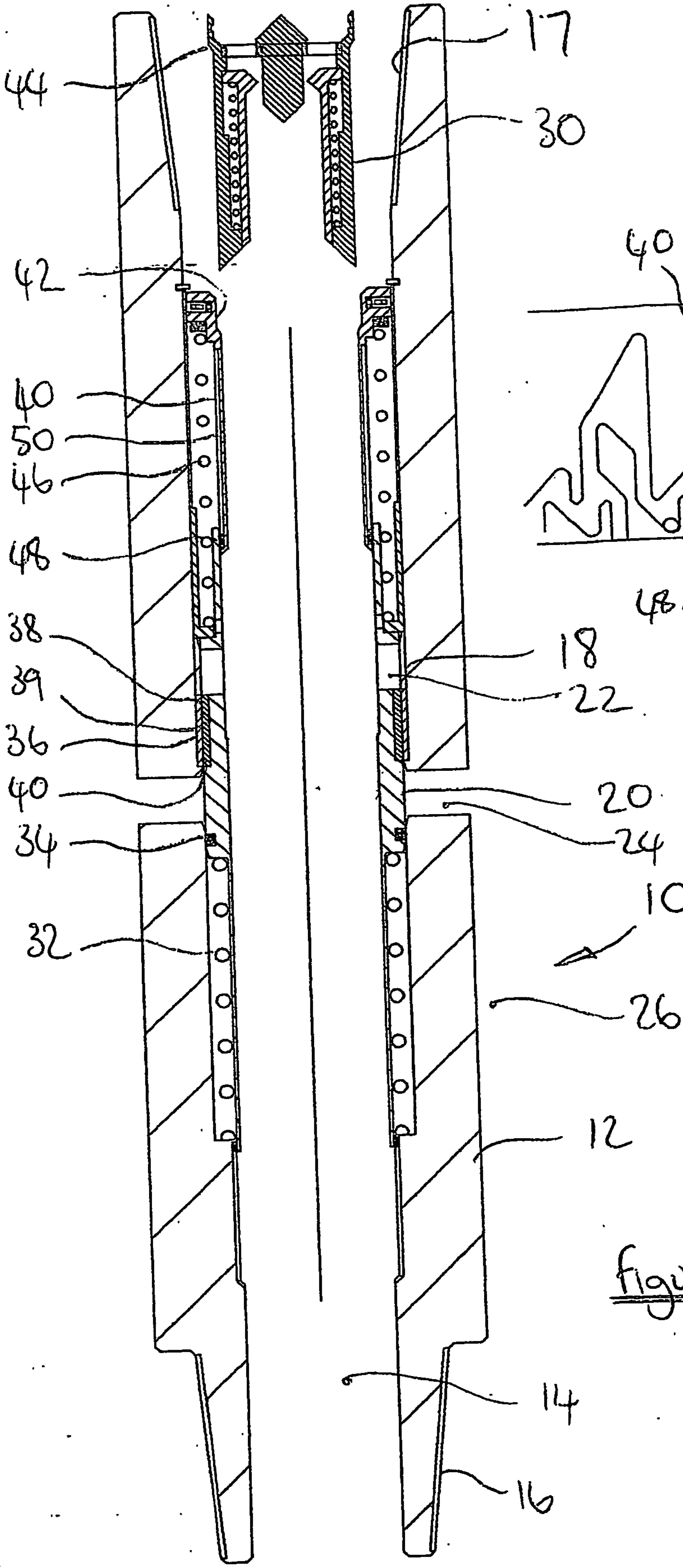


figure 4a

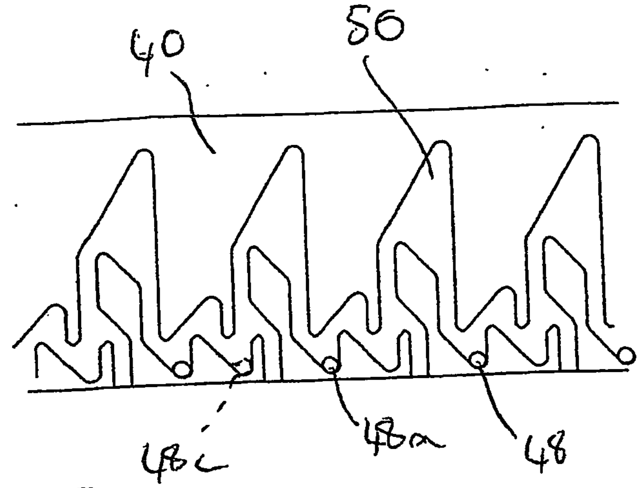


figure 4b

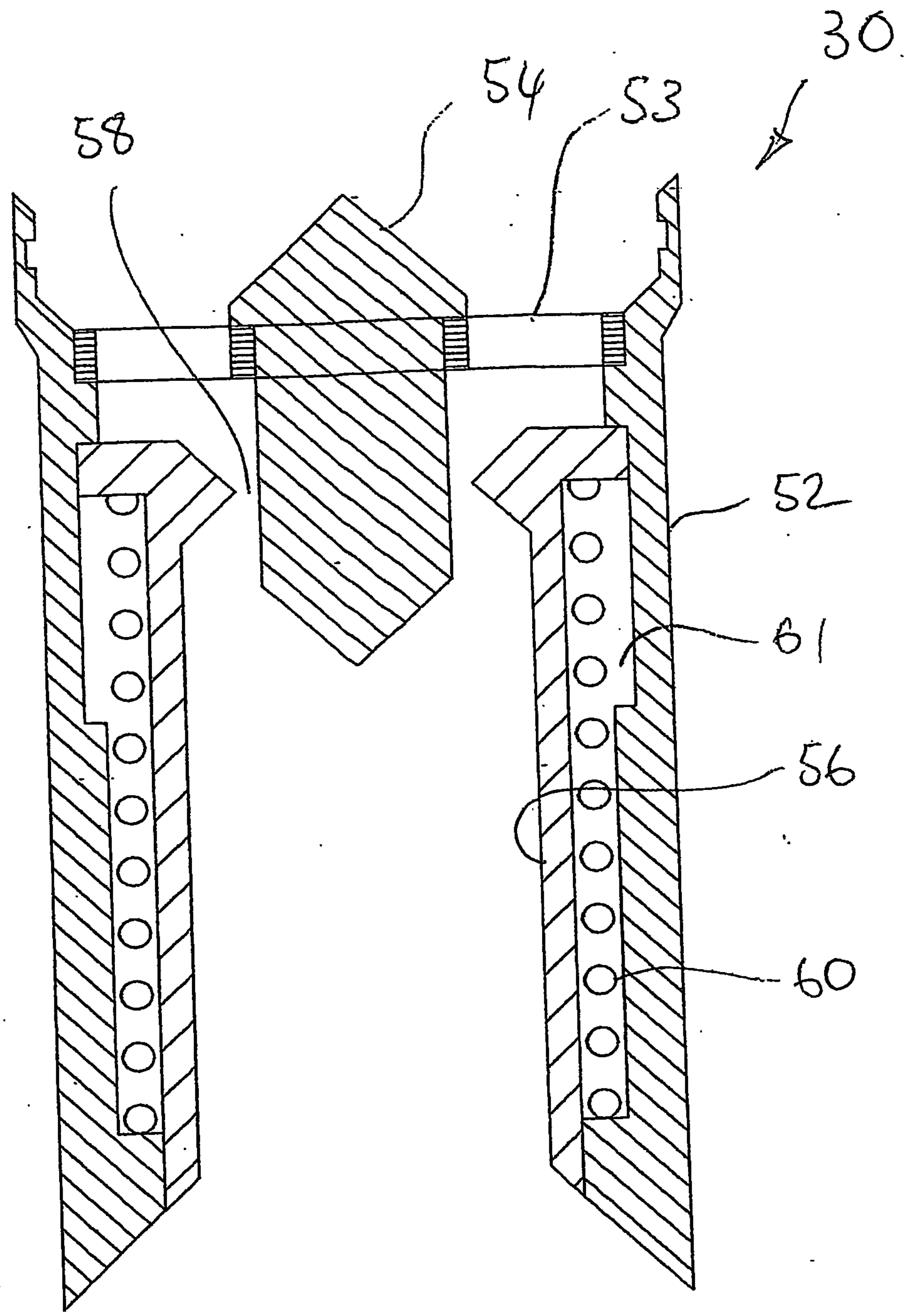


figure 4c

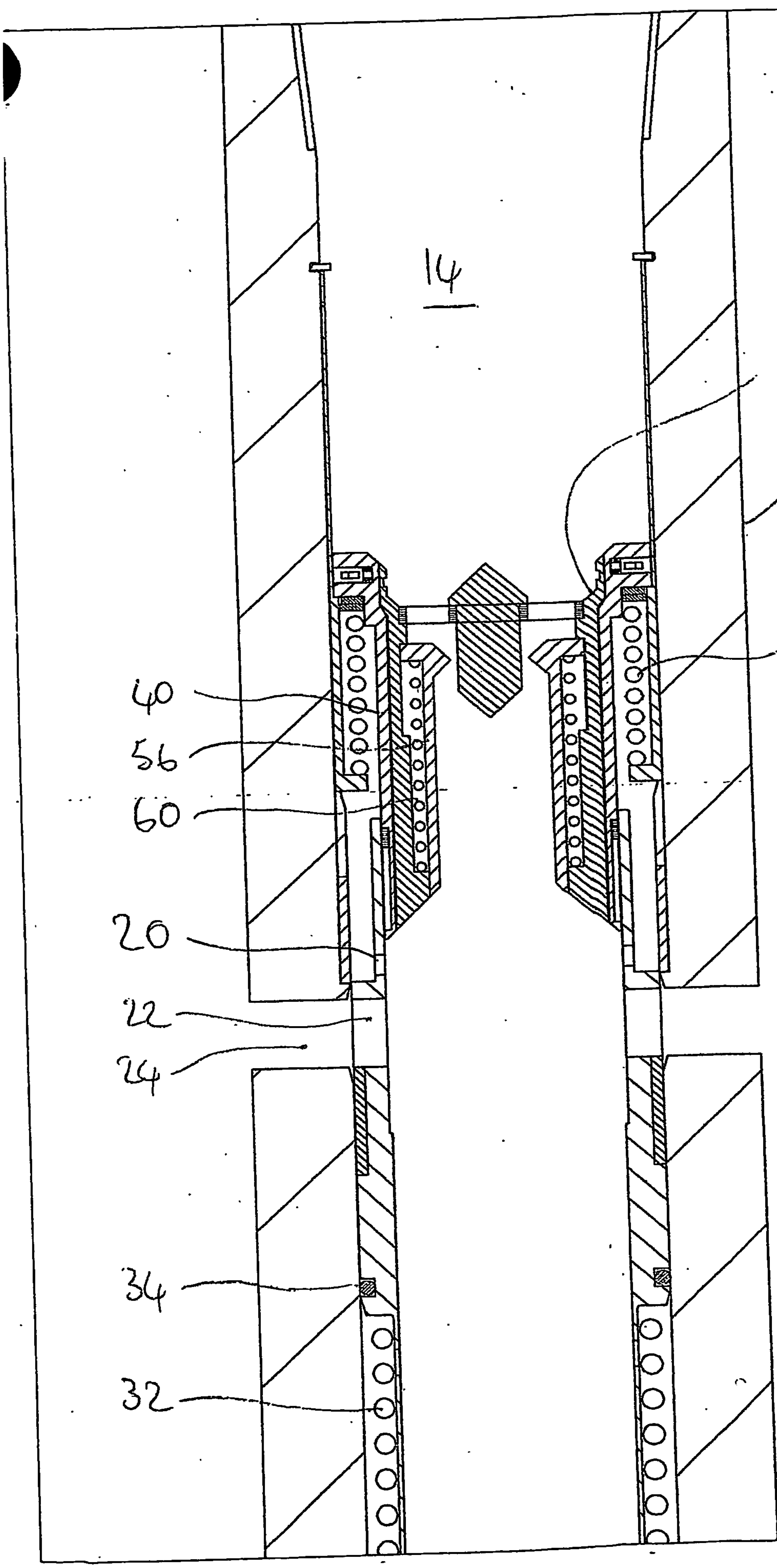


figure 5a

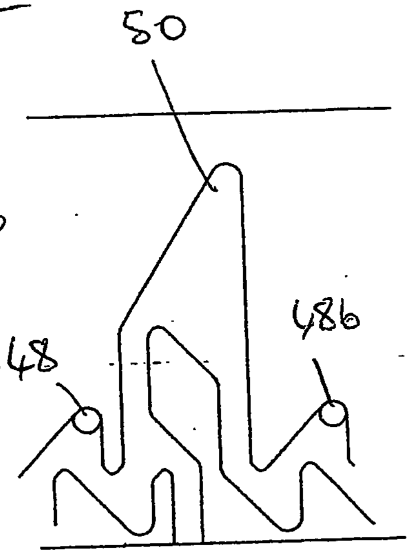


figure 5b

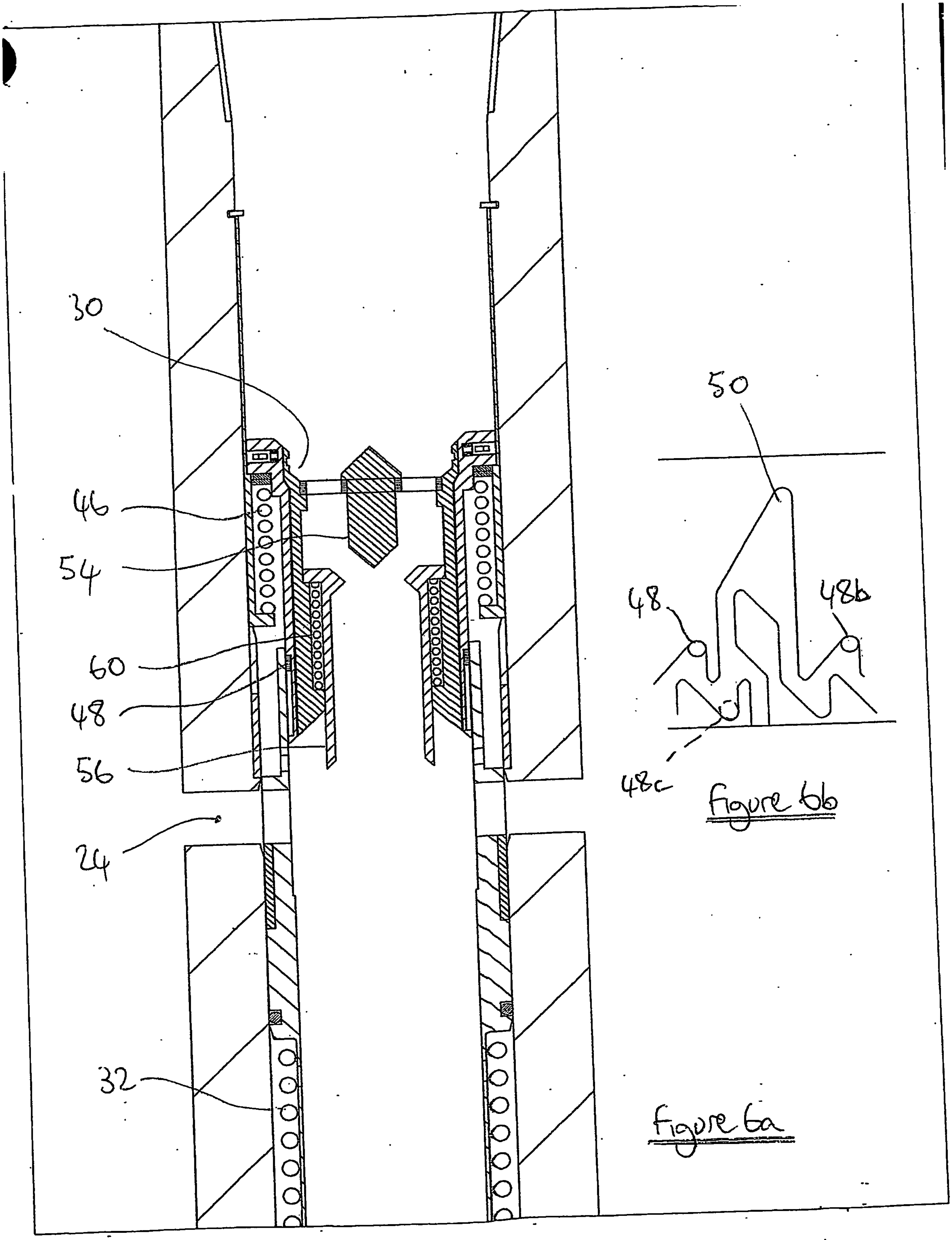


figure 6b

figure 6a

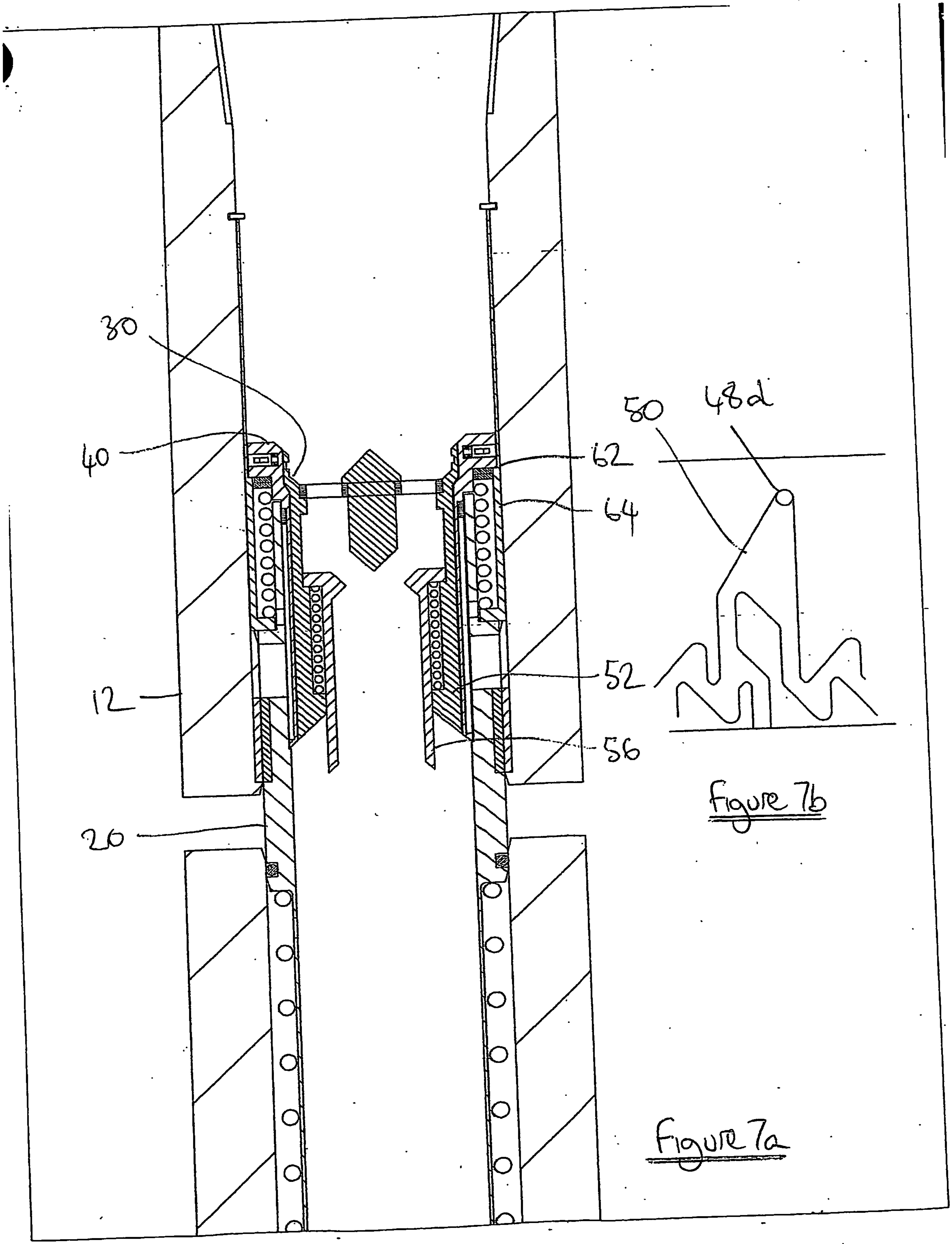


Figure 7b

Figure 7a

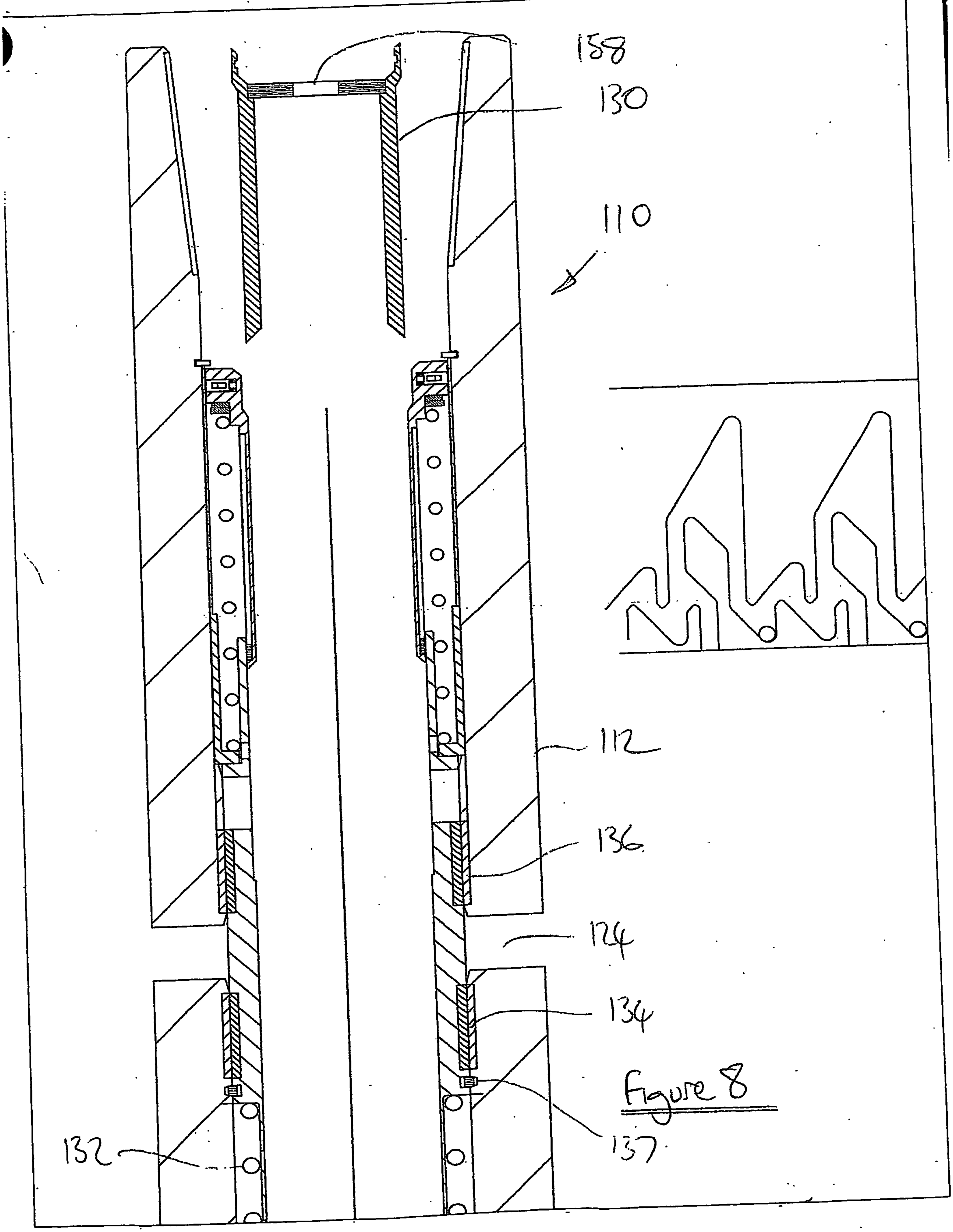


figure 8

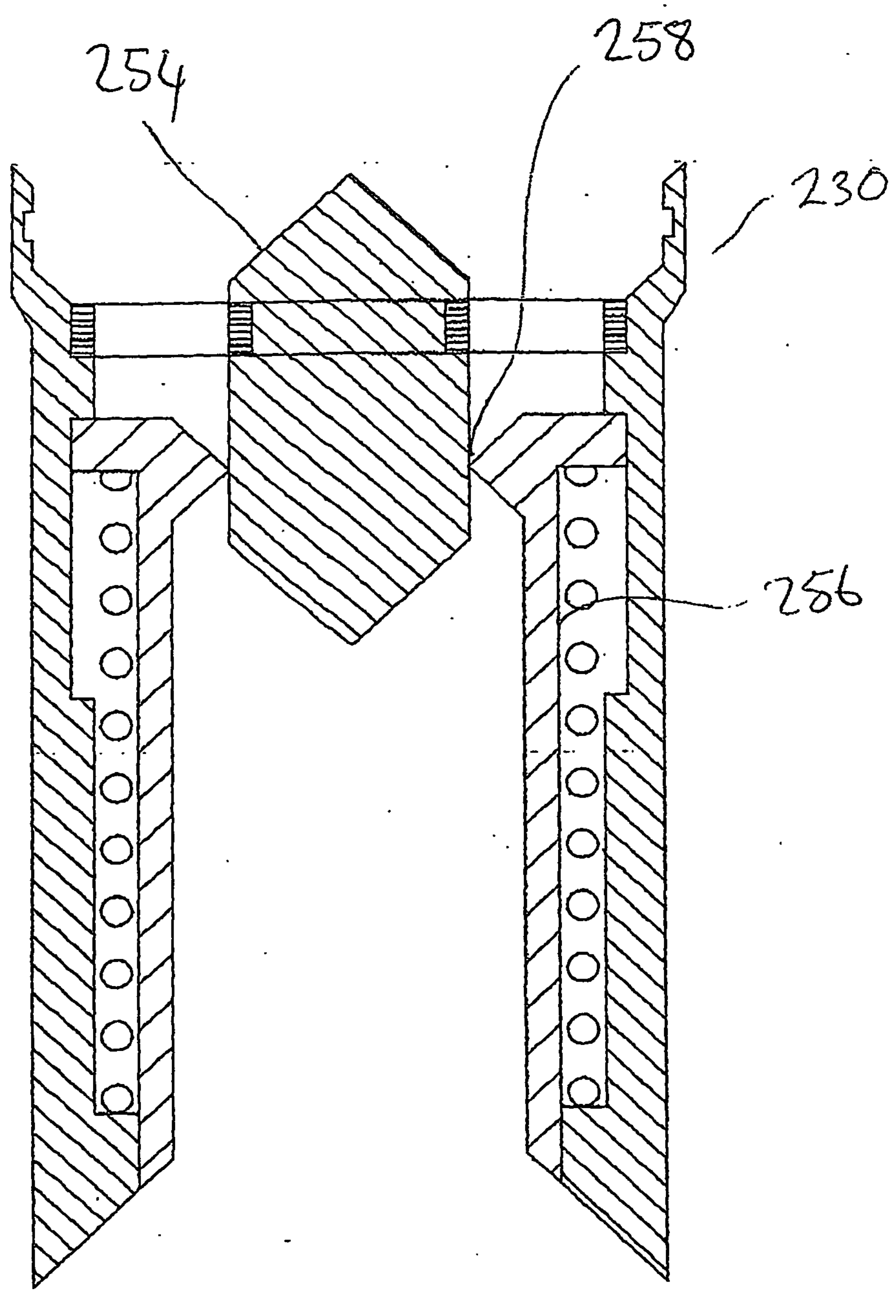


Figure 9

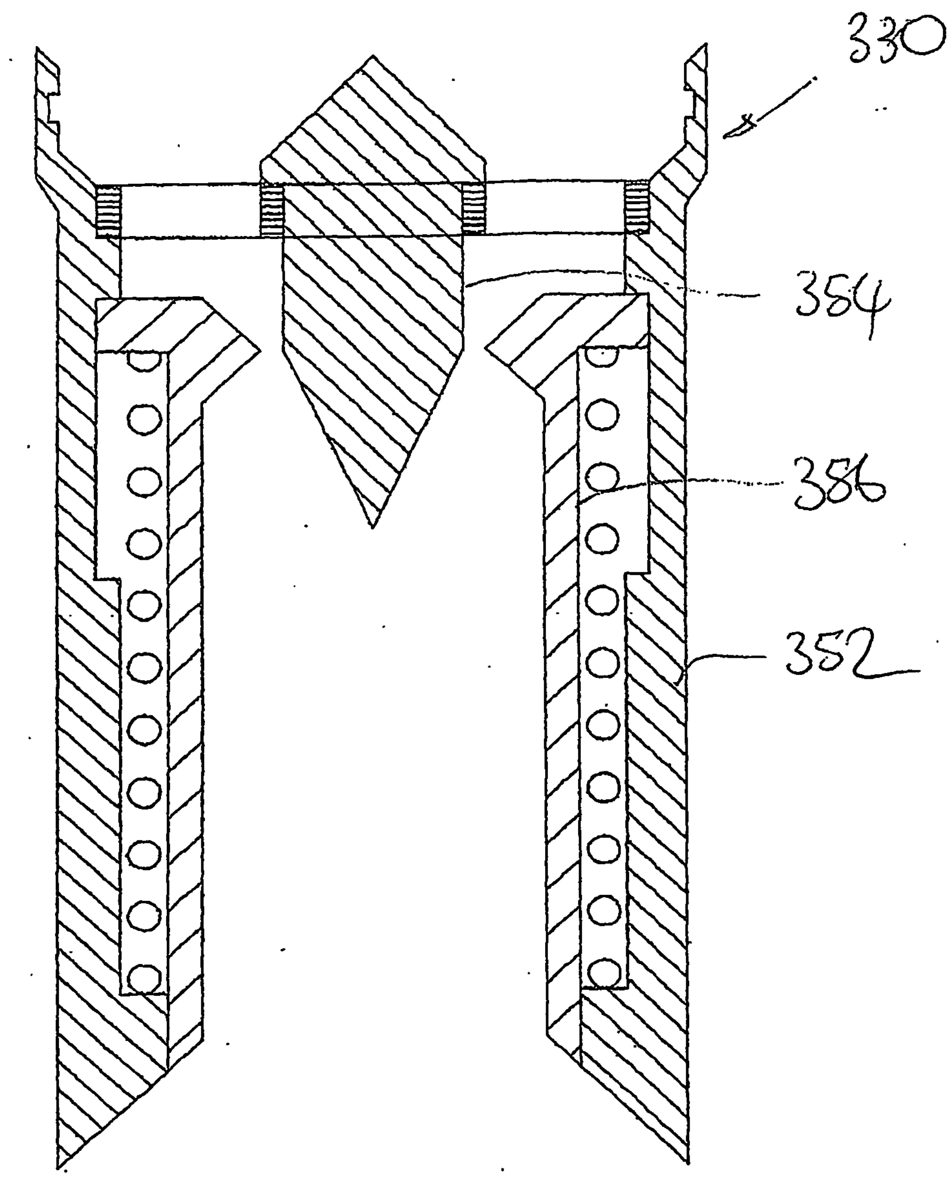


Figure 10

Fig 1.

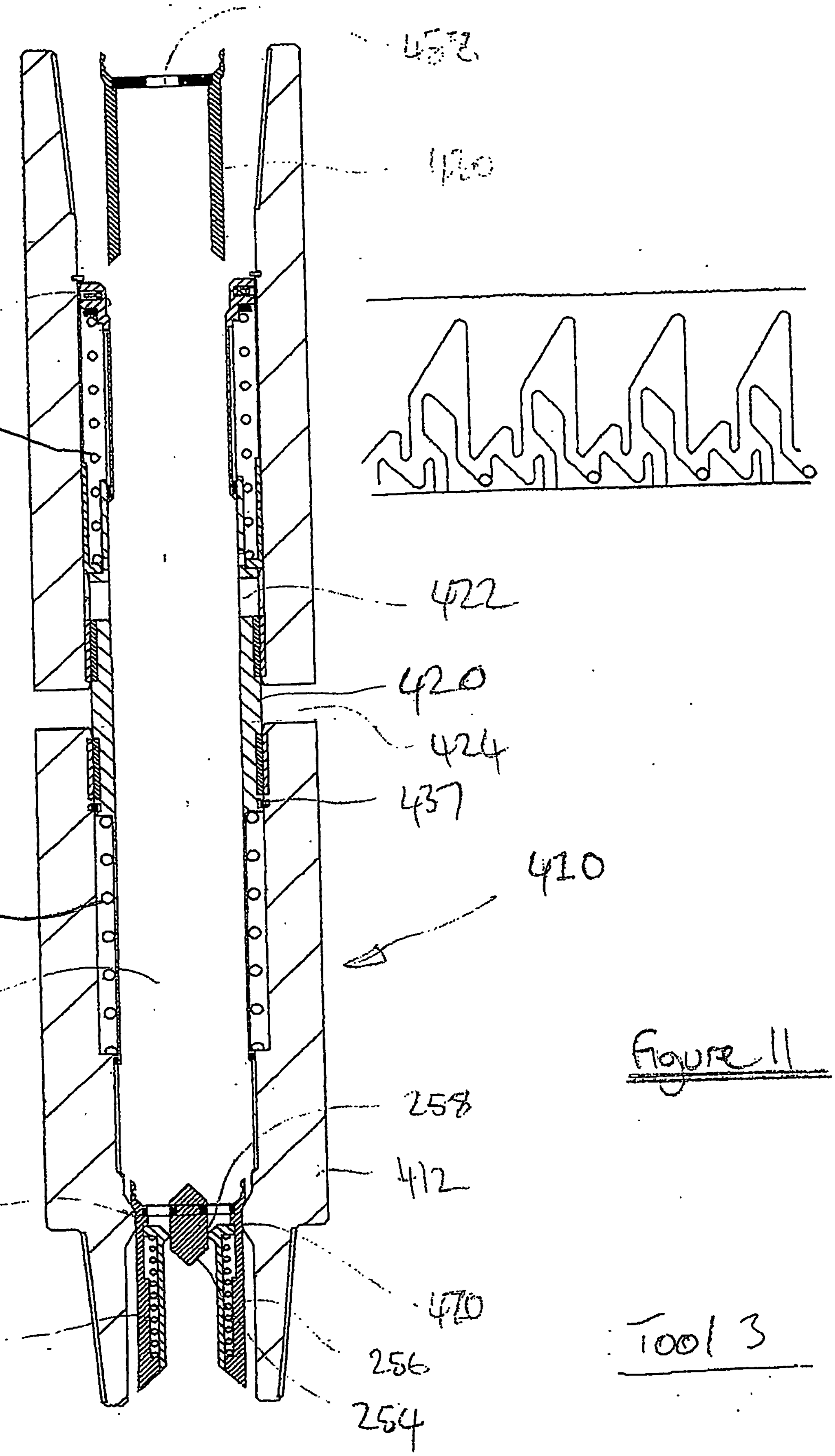


Figure 11

Tool 3

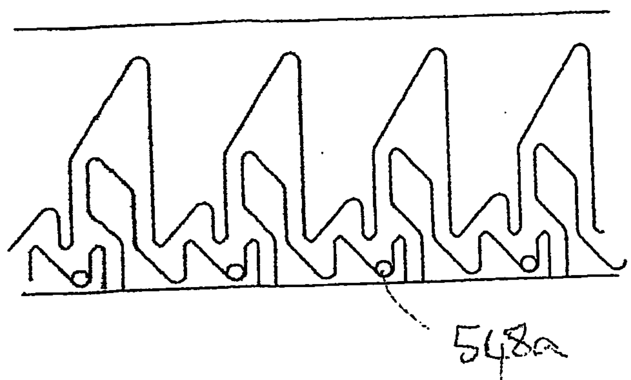


Figure 12b

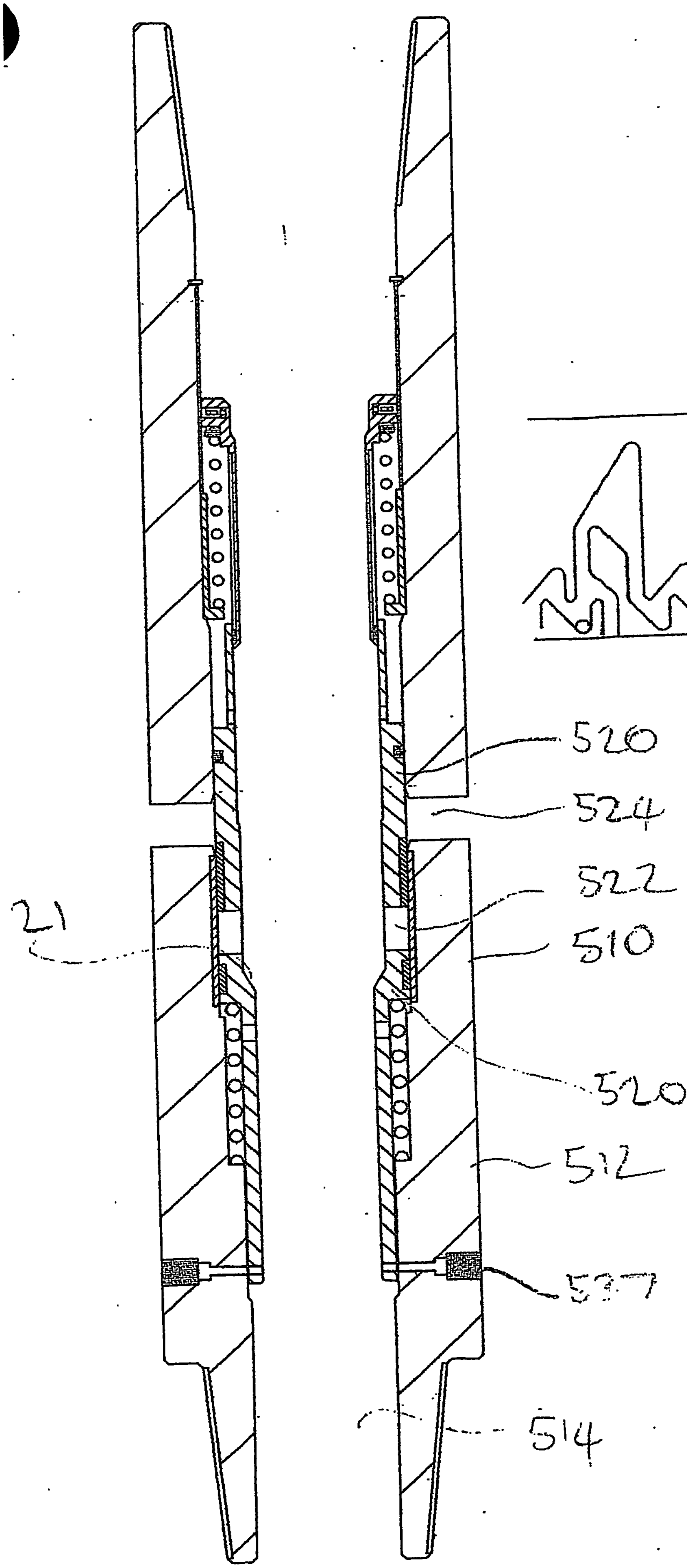


Figure 12a

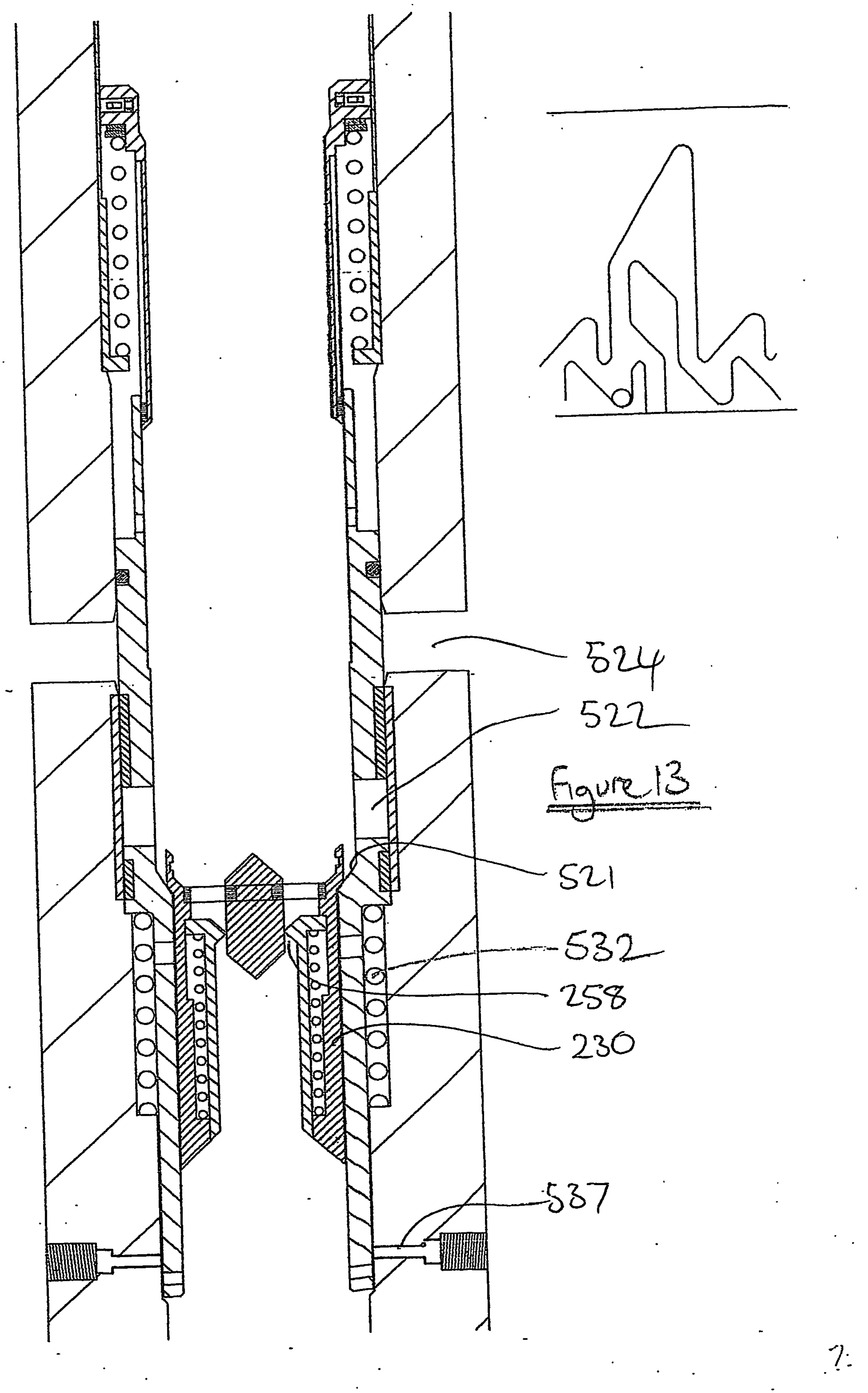


Figure 13

7.

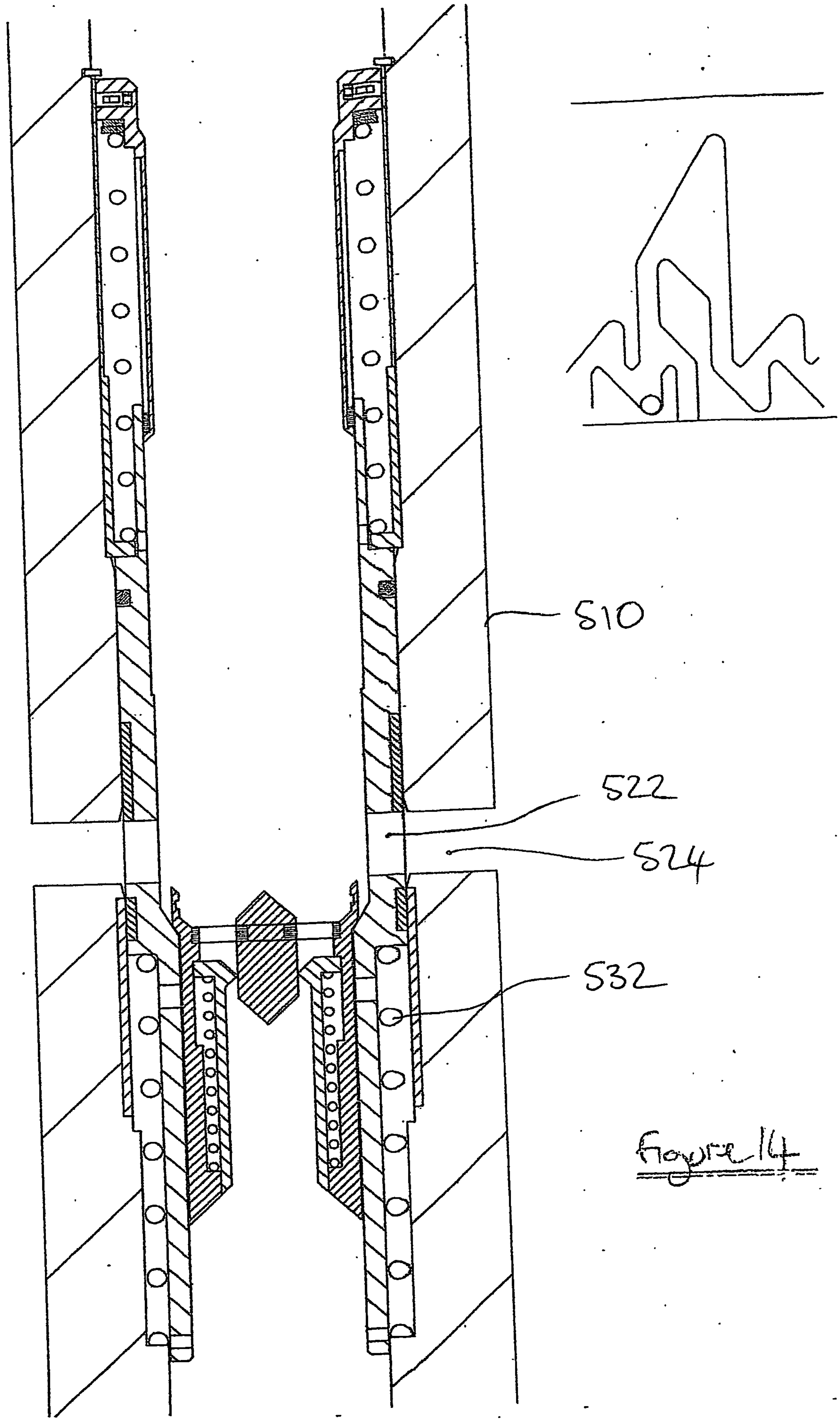
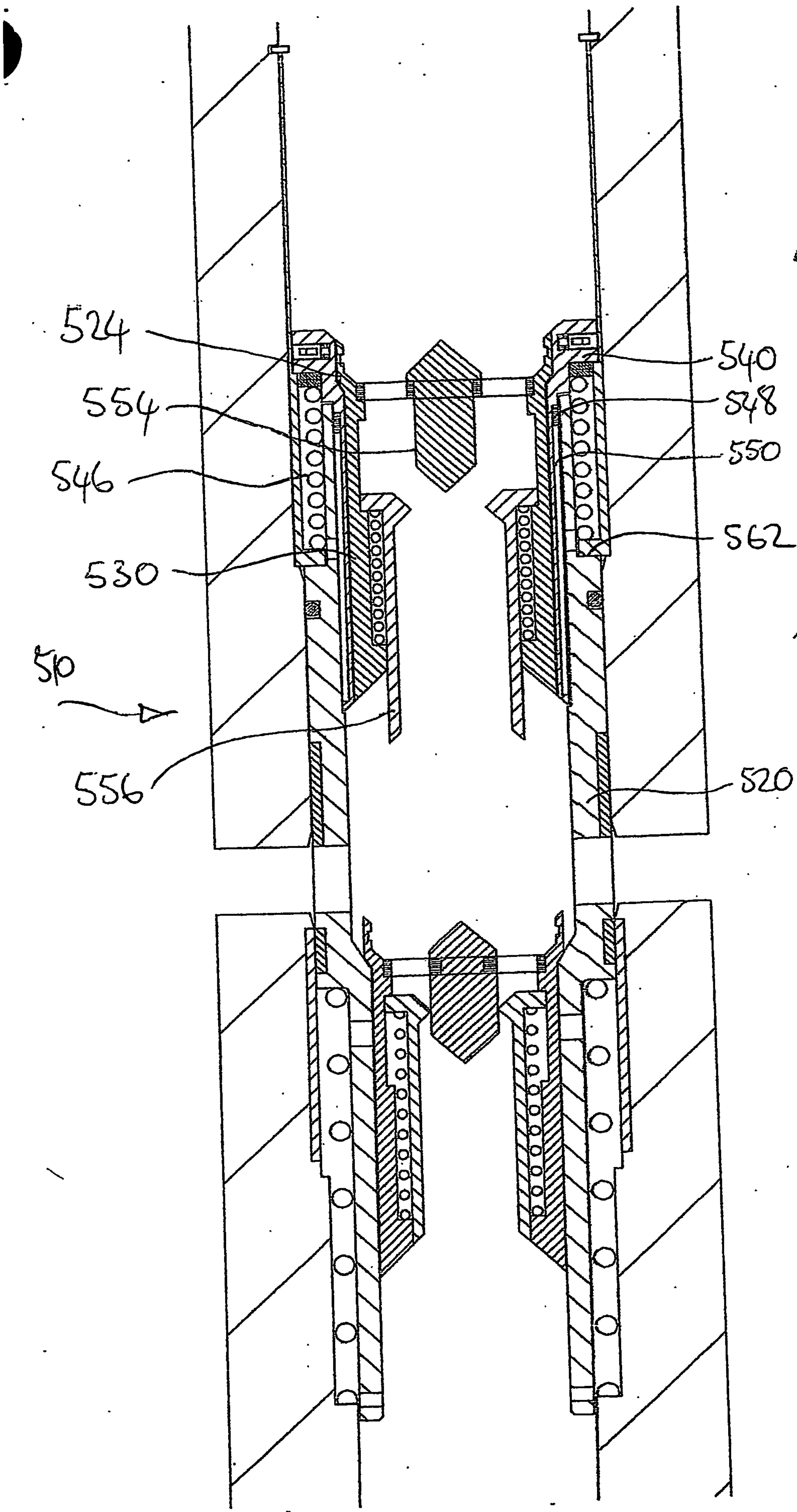


figure 14



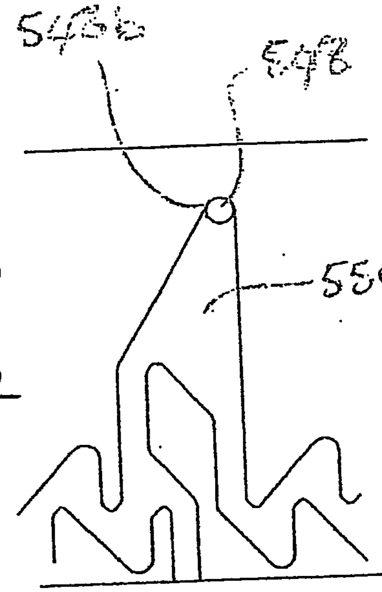
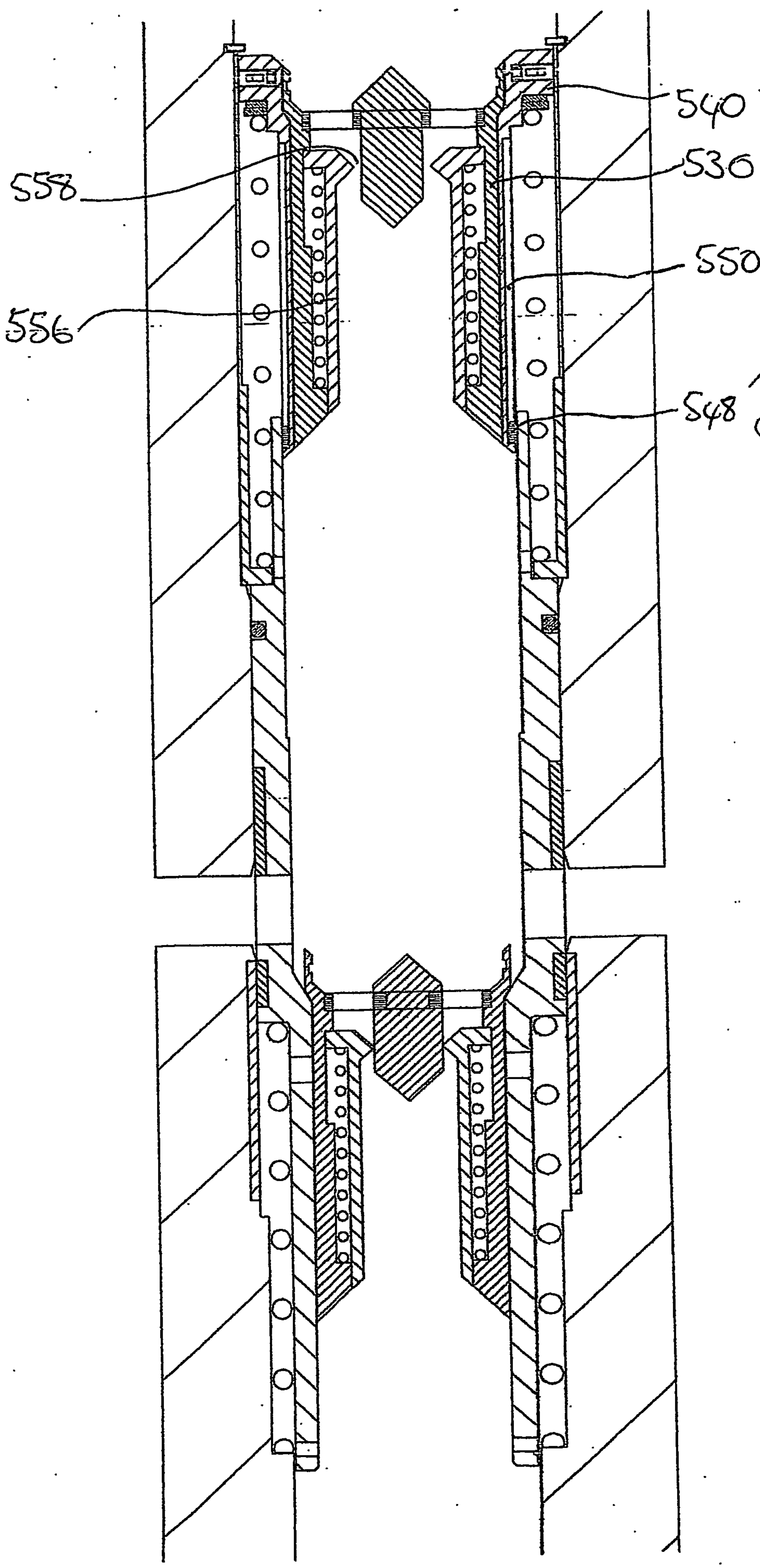


Figure 15b

Figure 15a



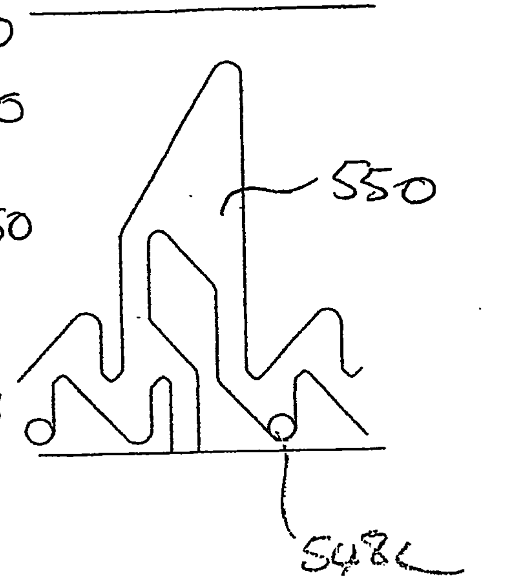
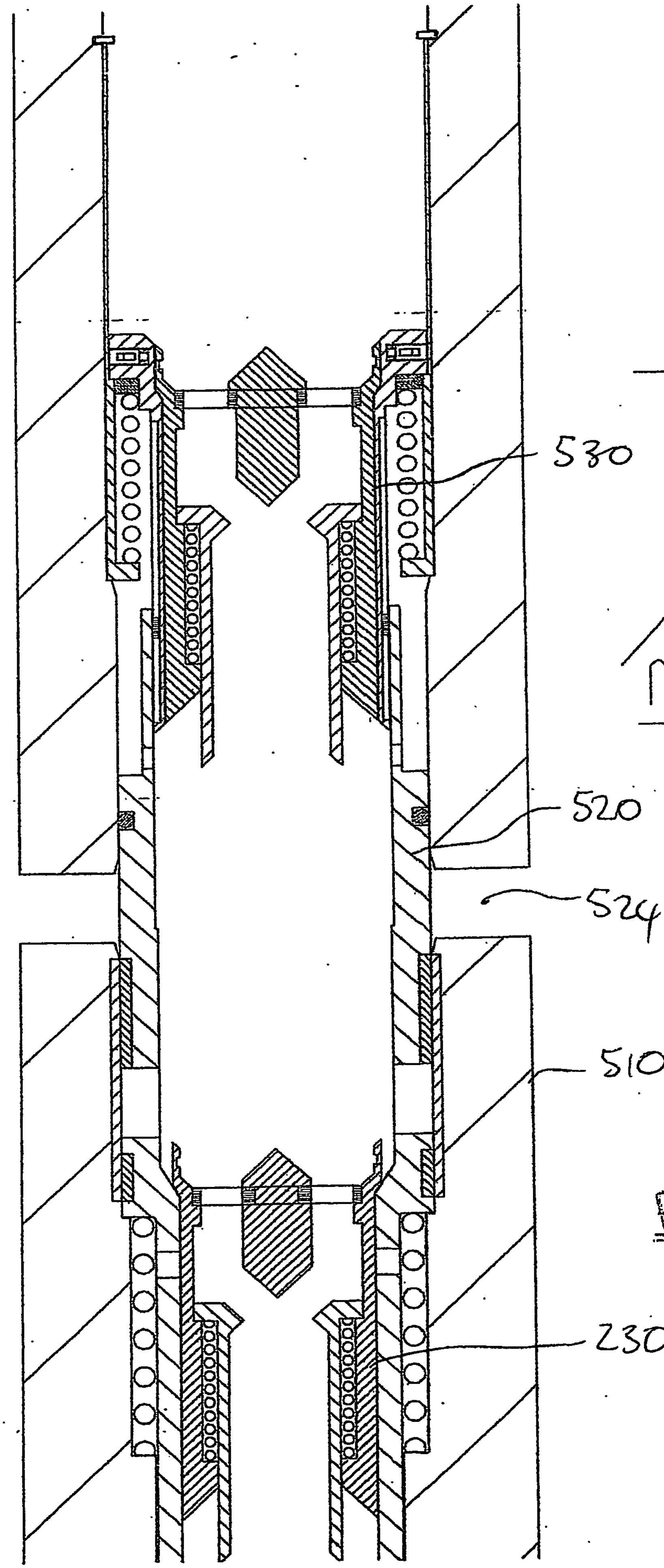


Figure 16b

Figure 16a



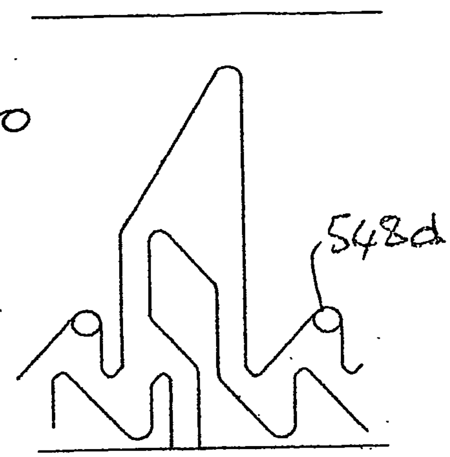
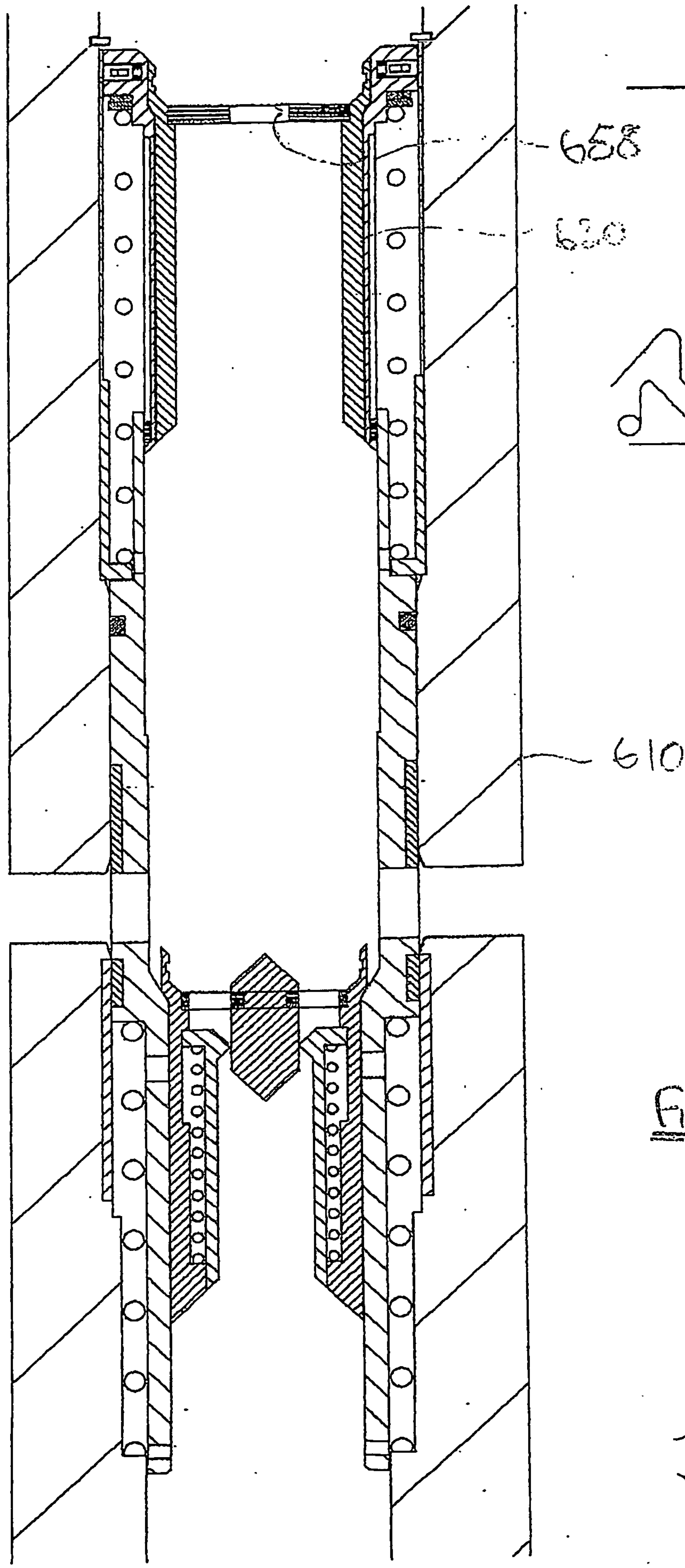


Figure 17b

Figure 17a



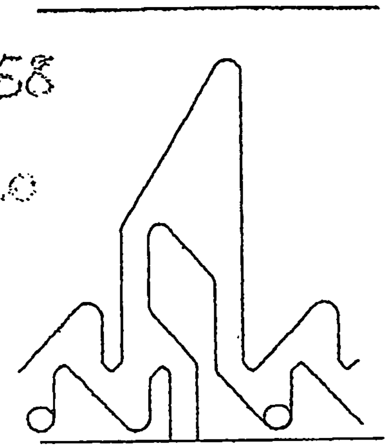


Figure 18

Tool 2

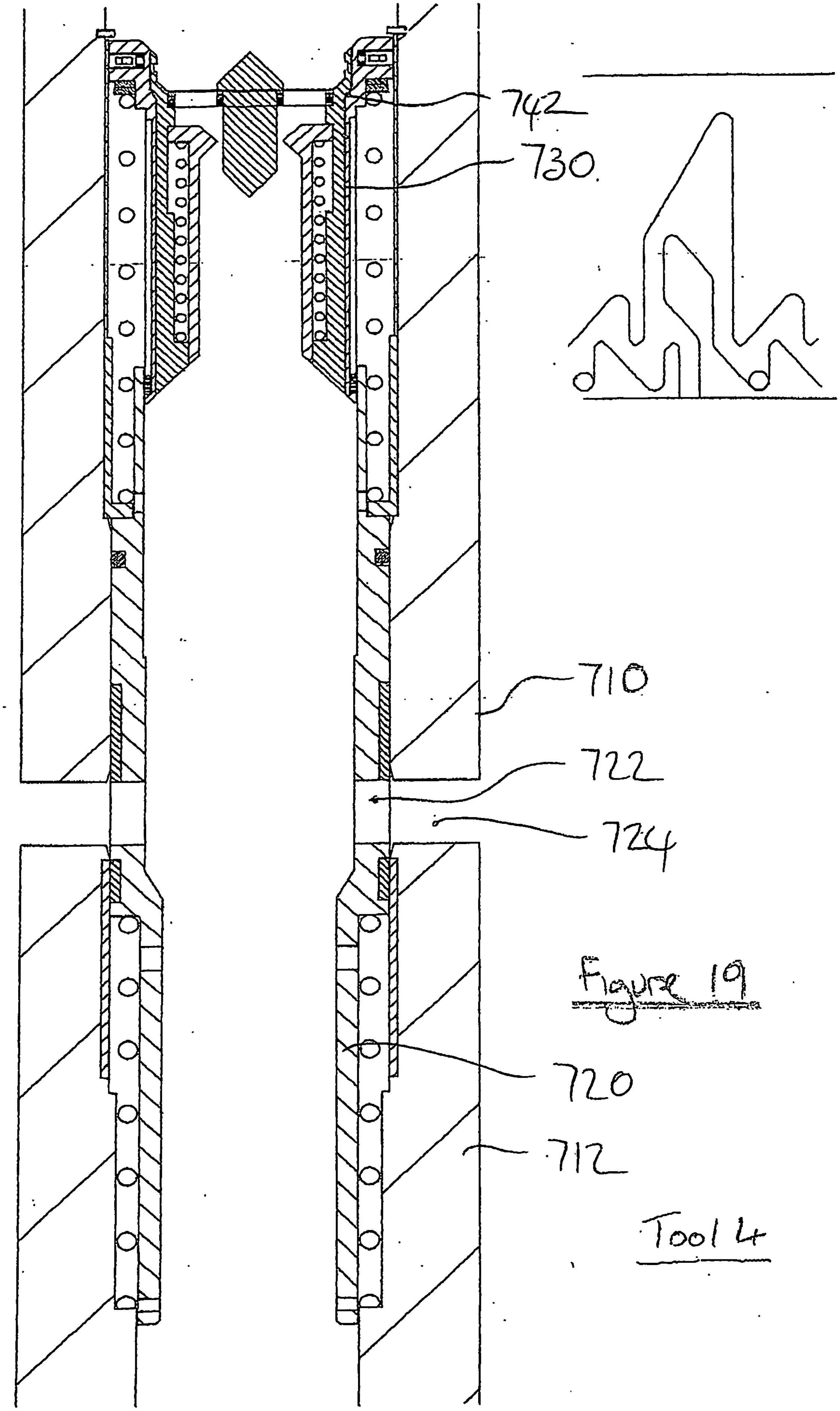


Figure 19

Tool 4

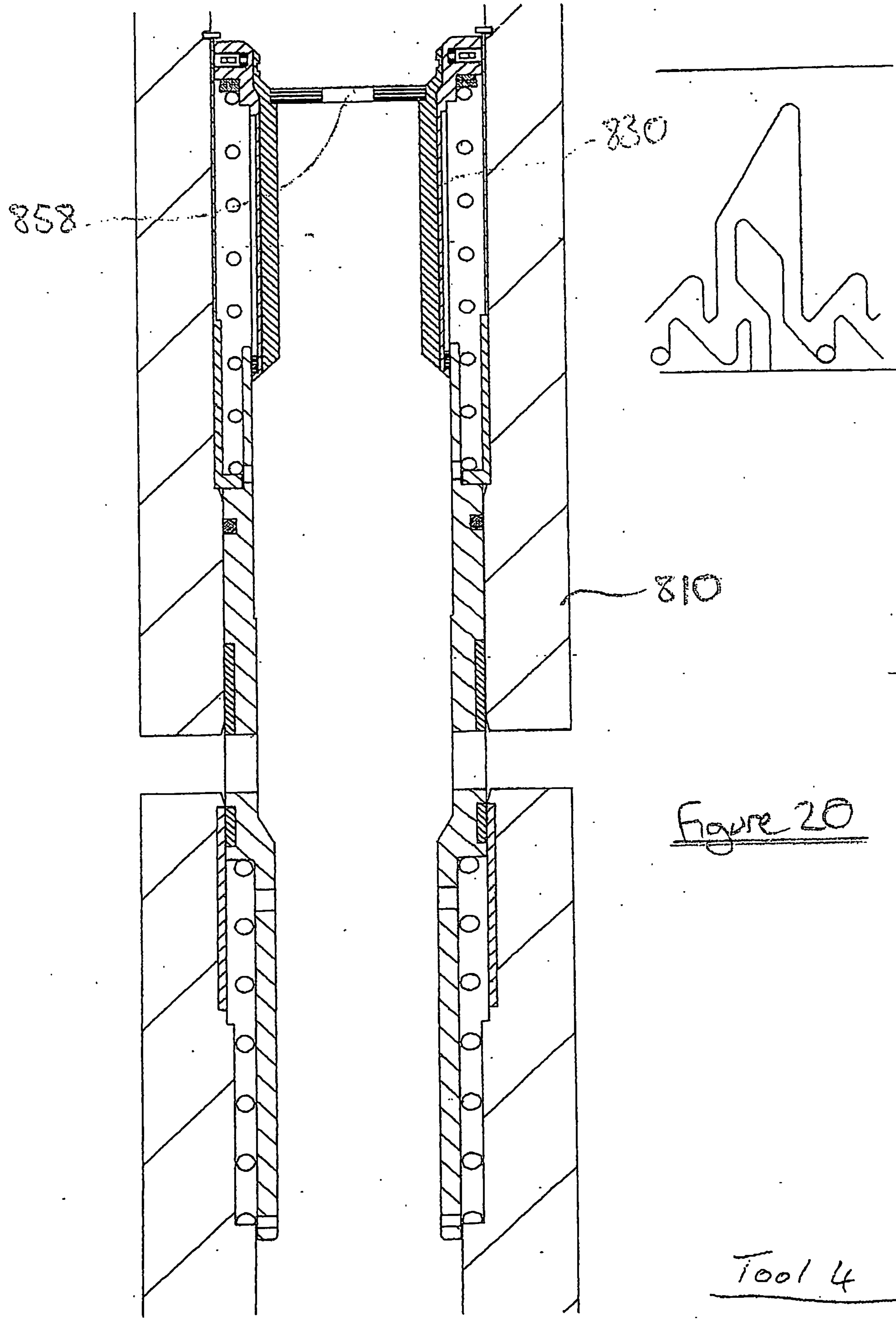


Figure 20

Tool 4

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